DETERMINATION OF THE RESISTANCE OF CONCRETE TO ABRASION AND IMPACT BY ICE UNDER OFFSHORE AND ARCTIC CONDITIONS

FINAL REPORT

BY

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ABSTRACT

This report describes the development of a laboratory test to evaluate the effects on concrete of ice impact and abrasion. This apparatus is unique in that it permits testing the combined effects of ice abrasion and ice impacts against rotating concrete cylinders of large dimensions for test specimens.

The properties of concrete specimens cast for this test are described. The test apparatus and the procedures used during testing are described. Initial results obtained during 166 hours of testing on one set of concrete specimens and during 80 hours of testing on a second set are reported, and conclusions obtained.

Recommendations are provided for additional testing to further develop the data base following minor modifications to the test apparatus.

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1. INTRODUCTION

The objective of this project was to develop a laboratory test to evaluate the effects on concrete of ice impact and abrasion, and to begin to establish a database covering a range of test conditions and materials.

During the first phase of the program, reported in Reference [1], a literature study was performed to assess the properties of concrete and methods of testing at low temperatures. The requirements of the test including apparatus specifications and concrete specimen design were established. Using these design requirements, various concepts were developed and examined and one concept was selected for further development. Detailed design, instrumentation and control plans were prepared and approved as well as detailed procedures for ice and concrete preparation, testing and data collection procedures. The design of the test apparatus permits testing the combined effects of abrasion and discrete ice impacts.

In this report the apparatus, as built, is described. The concrete specimens are described fully, including strengths obtained from compression test results. Four concrete specimens have been tested, the procedures used for testing these specimens and the methods used to measure the wear occurring on the specimens are discussed. The results of these tests are reported and conclusions drawn.

Recommendations are made for making a minor modification to the apparatus and for testing the remaining 22 concrete specimens to develop the database.

2. CONCRETE AND ICE PREPARATION

A series of concrete mixtures were cast at Laboratoire de Beton, Montreal using a laboratory mixer. The properties of the fresh and hardened concrete were determined and a number of cylindrical specimens were cast for testing.

2.1 Concrete Mix Properties

Portland cement (ASTM Type 1), low-calcium fly ash from a source in Nova Scotia, and silica fume from a Quebec source were used in the concrete mix. Physical properties and chemical analysis are provided in Table 2.1.

The coarse fraction of the aggregate consisted of 19-mm crushed limestone, or expanded shale lightweight aggregate, and the fine fraction was natural sand. The grading and physical properties of both the fine and coarse aggregate are given in Appendix A.

A sulphonated hydro-carbon type air entraining admixture was used in all the mixtures. A sulphonated naphthalene formaldehyde condensate superplasticizer of Japanese origin was used. It is usually available as 42% aqueous solution with a density of 1200 kg/m^3 and is dark brown in colour. The chloride content is negligible.

2.2 Specimen Design

Cylindrical concrete specimens were designed so that abrasion could be carried out against its rotating surface. Specimen dimensions were chosen as 300 mm diameter by 500 mm length to create the largest specimen that could easily be handled by two men in the laboratory. The approximate mass of the specimen as cast was 100 kg.

The design of the concrete specimen is shown in Figure 2.1. Normal 9.5 mm (3/8") rebar was used internally as indicated for strength and to transfer the torsional loads from the axle to the concrete. On sample number 3 an additional section of rebar was added, as shown, in order to provide a location for strain gauges. Gauges were placed on the axle, inner rebar and outer rebar as indicated in order to measure the response of the specimen to impacts. In order to mount these gauges it was necessary to smooth the rebar in the immediate location of the gauge which may have had some effect on the adhesion between the bar and the concrete. Figure 2.2 shows a completed reinforcement cage ready for strain gauging.

It should be noted that the specimens were cast in batches of two. Further details on the specimen preparation and details of the moulds are provided in Appendix A.

TABLE 2.1

PHYSICAL PROPERTIES AND CHEMICAL ANALYSIS
OF CEMENTS, FLY ASH AND SILICA FUME

	Normal Portland Cement* (ASTM Type I)	Fly Ash (Class F)	Silica Fume**
PHYSICAL PROPERTIES			
Fineness			
- Passing 45 μm sieve	84.7%	-	-
- Surface area, Blaine	354 m^2/kg	289 m^2/kg	-
- Surface area, Nitrogen	-	-	20,000 m^2/kg
Vicat Setting Time - Initial	125 min	-	-
Autoclave Expansion	-	-	-
Compressive Strength (50 mm cubes)			
- 3 day	22.2	-	-
- 7 day	27.4	-	-
- 28 day	35.5	-	-
Pozzolanic Activity Index			
- Cement - water requirement	-	97%	-
- Activity index, 28 d	-	94%	-
- Lime - Acitivity index, 7 d	-	6.7 MPa	-
CHEMICAL ANALYSIS			
Silicon dioxide (SiO_2)	21.0	44.93%	94.0%
Calcium dioxide (CaO), total	4.5	0.92%	0.50%
Aluminum oxide (Al_2O_3)	3.0	25.79%	0.06%
Ferric Oxide (Fe_2O_3)	62.4	19.06%	0.03%
Magnesium oxide (MgO)	2.2	1.43%	1.10%
Sulphur trioxide (SO_3)	3.3	3.16%	0.50%
Sodium oxide (Na_2O)	0.26	0.82%	0.02%
Potassium oxide (K_2O)	0.94	0.54%	0.20%
Loss on ignition	1.80	2.88%	2.50%
Insoluble Residue		-	
Bogue Potential Compound Composition			
C_3S	50.5	-	-
C_2S	22.1	-	-
C_3A	6.8	-	-
C_4AF	9.2	-	-

* Typical test data supplied by manufacturer
** CANMET data

Figure 2.1
Concrete Specimen Design

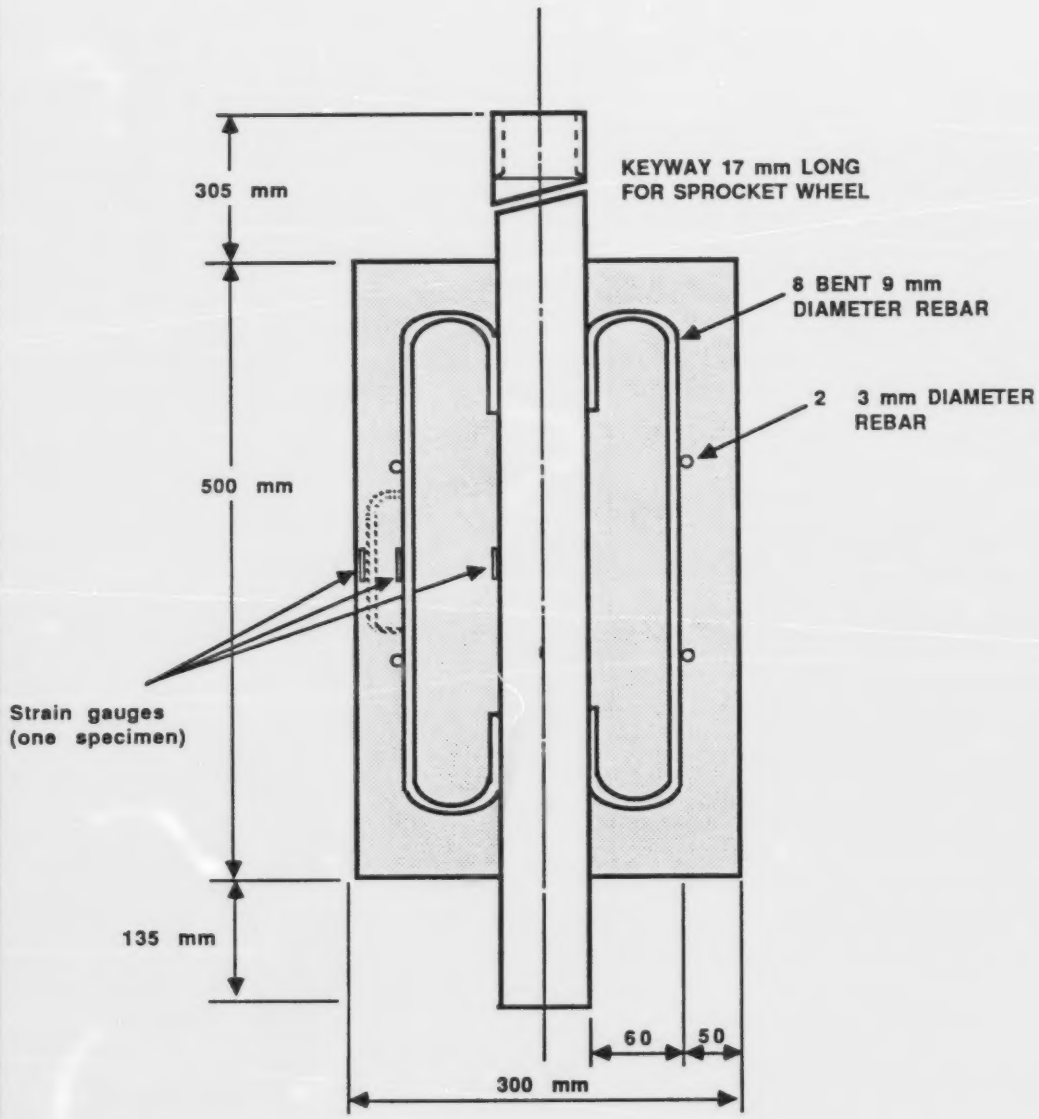
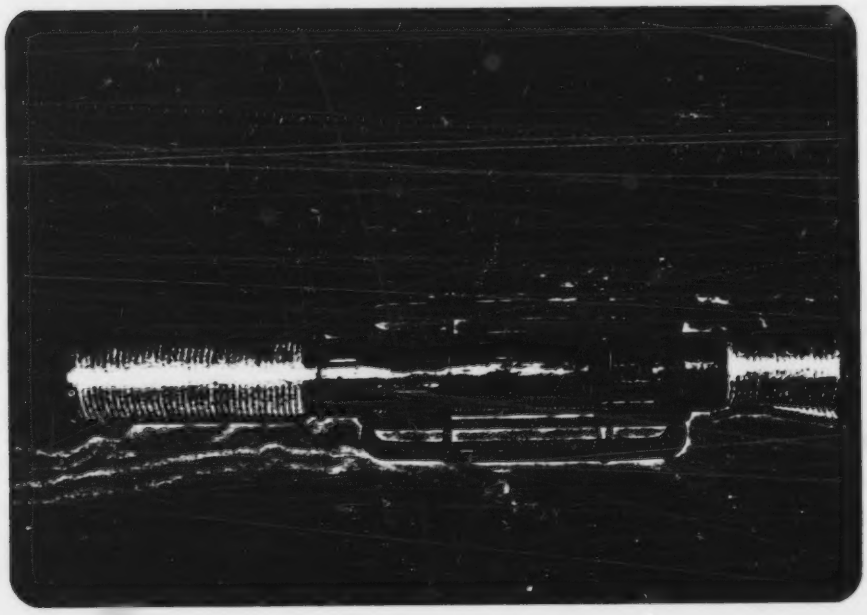


FIGURE 2.2

THE SPECIMEN SHAFT AND REINFORCING CAGE



2.3 Surface Finish

Two surface finishes were used for the concrete. A smooth finish was obtained by casting concrete against the steel mold. An artificially rough finish was obtained by casting it against a plastic surface of the same type used as a diffuser on fluorescent lighting. This surface had regular smooth 'dimples' about 3 mm deep at spacings of 3 mm, similar to a golf ball. Both surface finishes were smooth on a scale of concrete particle size as the concrete paste conformed to both surfaces. Initially there were no sharp irregularities to be pulled out of the matrix, although small bug holes (up to 10 mm in size) were evident. Figures 2.3 (a) and (b) respectively show rough and smooth textured samples as cast.

2.4 Compression Testing of Control Specimens

Three 150 x 300 mm cylinders cast from each mixture were tested in compression at 7, 28, 90 and 120 days. All specimens for compression testing were capped and tested in accordance with standard ASTM methods. The 28-day test results are given in Appendix A.

2.5 Ice Preparation

Ice blocks were prepared in accordance with procedures described in Ref. [1]. The ice salinity achieved during the present program was in the range from 3 to 5 ppt which compares with typical salinity levels of the order of 2 to 5 ppt for naturally occurring first year sea ice.

Ice was grown to a thickness of 550 mm and was cut down to 350 mm to fit the width of the ice retainer box. The remaining ice of 200 mm thickness was stacked together to fit the width of the retainer and was refrozen into the retainer box, thus permitting more efficient use of the ice sheets. Prior to fitting the ice into the retainer box it was machined by a router on all sides. An accuracy of 10 mm was achieved on the sides to facilitate fitting into the retainer, and an accuracy of 5 mm between the parallel top and bottom surfaces ensured even initial contact against the concrete samples. The saline ice was placed into the retainer box and the gaps between the ice and the box walls were filled with water before refreezing the ice. This formed a secure method to hold the ice in the retainer.

FIGURE 2.3 (a) AS-CAST ROUGH TEXTURED SAMPLE

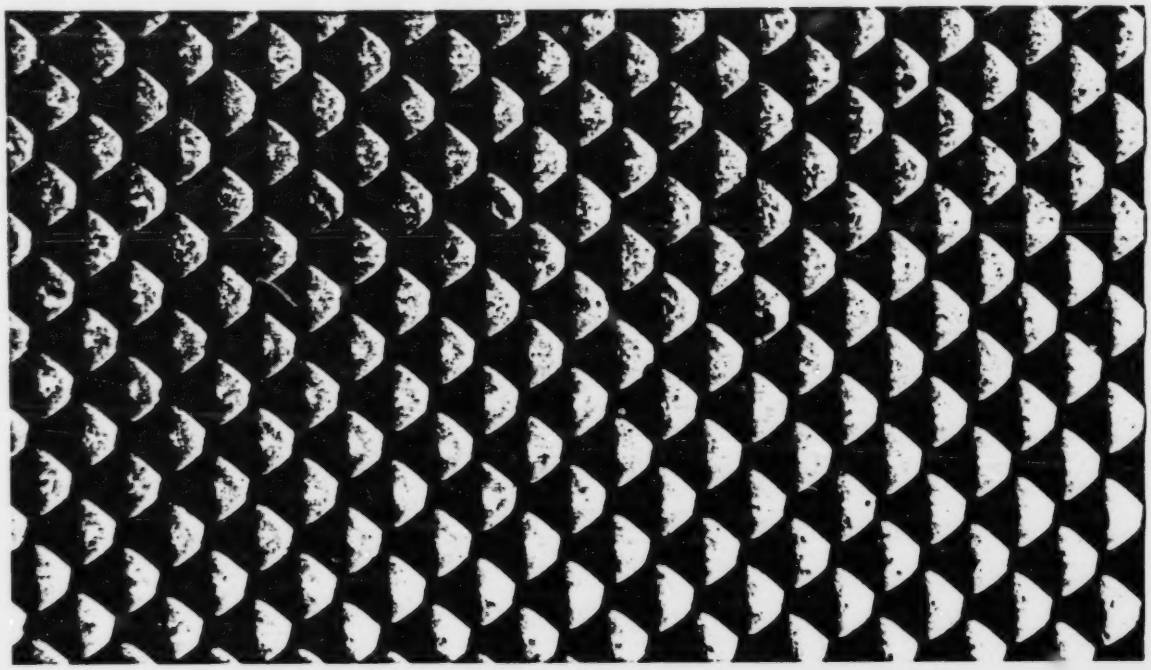
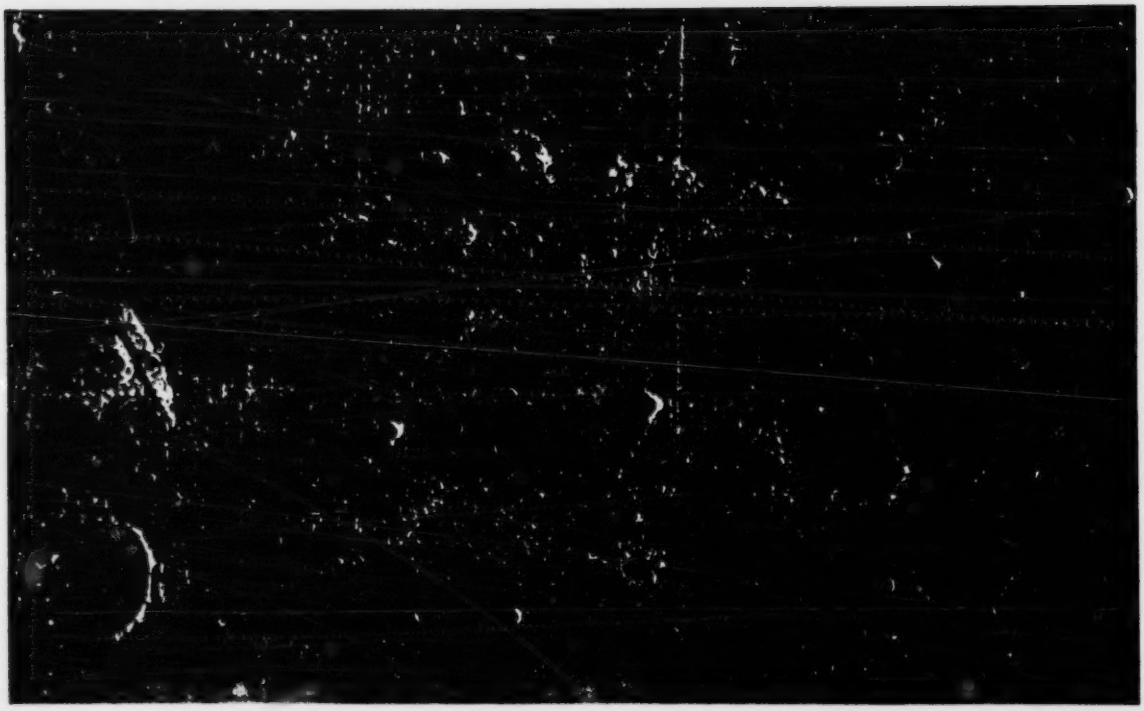


FIGURE 2.3 (b) AS-CAST SMOOTH TEXTURED SAMPLE



3. DESCRIPTION OF THE TEST APPARATUS

The test apparatus was built in accordance with the detailed design specifications developed in Phase I [Reference 1]. The apparatus was designed to provide the following functions:

a) ice impact at speeds of up to 2 m/s

b) ice abrasion at sliding speeds of about 1 m/s

c) combined/sequential ice abrasion and impact.

Figure 3.1 illustrates the test apparatus as assembled in the cold room. The figure shows two concrete samples fitted in testing position but there was no ice in the retainer box. Not shown is the drive system consisting of motor, gear reduction unit, and chain drive which drives two sprockets fitted at the other end of concrete specimen's mounting shafts.

In the following paragraphs various operational considerations will be discussed:

a) Concrete Specimen Mounting

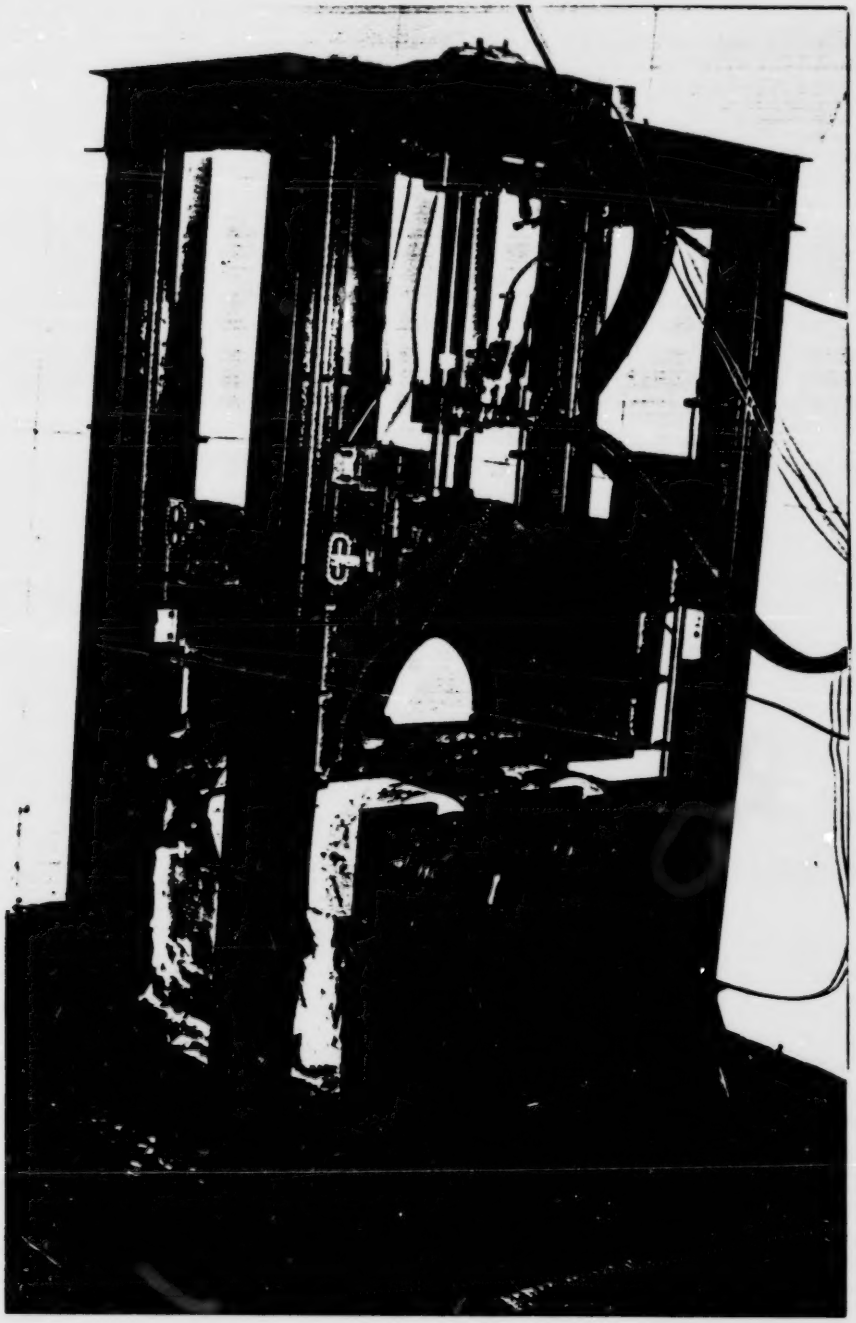
The concrete specimens are mounted in large capacity spherical bearings on a lower frame to safely transmit impact forces to the floor. A 5HP 220V three phase electric motor is used to rotate the concrete specimens. The drive system consists of a 20:1 worm gear speed reducer and a roller chain. Protection against overloads is provided by a friction clutch between the speed reducer and chain drive. Both specimens rotate in the same direction.

b) Ice Block Mounting

The ice block used for impact and abrasion has dimensions of 300 mm high x 800 mm long x 350 mm wide. This block is contained in a steel retaining box which slides vertically up and down along four guide rails. Side loads are supported by eight sliding roller bearings, as shown in Figure 3.1. Vertical movement in controlled by a 50 mm diameter, 600 mm stroke hydraulic ram with maximum operating pressures of 20.7 MPa (3000 psi). This ram is connected to a hydraulic power supply by 38 mm hoses to provide a high flow rate system. The ice block velocity downwards could exceed 2.5 m/sec, but is controlled by a flow restricting valve in the hydraulic power supply.

FIGURE 3.1

TEST APPARATUS AS COMPLETED



c) Temperature Requirements

A constant test temperature of -10°C was provided by installing the apparatus inside the Arctec Cold Room. This facility, with dimensions of 10 m x 5 m x 5 m, is insulated to provide working temperatures to -40°C. Cooling is provided by two refrigeration systems working in parallel, should a single system fail the remaining system is still capable of cooling the room to -30°C. Materials handling inside this facility was provided by a 1 tonne hoist and overhead gantry crane.

d) Concrete Wetting Apparatus

In order to permit abrasion between wetted concrete and ice and to prevent ice from forming on the concrete it was necessary to build a water bath beneath the concrete specimens as shown in Figure 3.1. A tank with dimensions of 540 mm x 820 mm x 310 mm was constructed from 4.3 mm plexiglass and mounted underneath the concrete in the apparatus. Fiberglas insulation was placed around the sides and underneath the tank to reduce heat loss. When filled to about 50 mm from the top the concrete became approximately one third immersed in this tank.

To prevent the water in this tank from freezing and to maintain its temperature at between 1 and 5°C a 120V, 600 W immersion heater was installed in the tank. The power to this heater was controlled by means of a Variac control. This was adjusted manually and after a short period of trial and error a stable setting was obtained which provided a steady water temperature of 2-3°C. This setting was generally in agreement with an initial calculation which had showed the heating requirements to be in the order of 100 W.

e) Control System

Two methods of control were used during testing. During abrasion testing without impact the system was permitted to run manually without computer control. A limit switch was used to shut the apparatus down when the ice block was worn away. The switch was tripped when the ice block retainer came within 50 mm of the water bath.

Computer control was used for impact testing. The microcomputer, also used for data acquisition, was used to control solenoid valves in the hydraulic power supply through a D-A converter and relays. This permitted digital logic to operate these valves, which controlled the vertical movement of the ice block. An interlock permitted the computer to be overruled and the ice block raised by switches located on the apparatus.

Impact speed and abrasion pressure were controlled manually using valves mounted on the hydraulic power supply.

4. TESTING

4.1 Preliminary Testing

Preliminary testing was performed to examine the process of ice abrasion and determine first hand estimates of the time requirements for testing concrete specimens to an appreciable level of deterioration. The earliest tests were performed under dry contact conditions, i.e. without immersion in water. Therefore, the temperature of both ice and concrete were maintained at approximately -10°C. It became apparent very early in the test that a thin ice layer was formed at the concrete surface and that this layer continued to grow to a stable thickness. Further abrasion or impact did not change the surface condition. Therefore, with the ice forming on the surface of the concrete no abrasion or surface deterioration was possible due to ice action.

As a result of this test it was concluded that dry abrasion conditions are not detrimental to the concrete as long as the protective ice layer is maintained. This is probably the case in the area of a structure above the splash zone, or under the conditions of a frozen water surface with no water wash action.

On the contrary, a wet abrasion condition would not permit an ice protective layer to form and would naturally invoke the mechanisms associated with ice abrasion on concrete. Hence, it was decided that no further testing was necessary under dry conditions and that only wet concrete tests should be performed.

A typical water temperature in the East Coast offshore is of the order of a few degrees and, therefore, a water bath containing sea water maintained at a temperature of 2-5°C would be adequate. This equipment is described in Section 3.

As a consequence of this wet testing arrangement, the concrete surface temperature was much warmer than -10°C and naturally, the ice temperature at the interface was also warmer and an ice block was consumed at an accelerated rate. The test duration was, therefore, extended and the rate at which ice blocks were used was much increased. It was necessary to revise the test plan to reflect this initially unknown parameter.

4.2 Test Matrix

Table 4.1 gives the test matrix which includes abrasion, impact and combined impact/abrasion tests performed on textured and non-textured concrete specimens. The abrasion speed was maintained constant during all tests and the impact speed was varied in two different sequences as outlined in the table. It should be noted that the concrete strength listed in column 2 for various types is the nominal strength. Measured strength data are reported in Appendix A. Table 4.2 gives proper reference of the test specimens to their respective type and batch. Therefore, specific properties, as measured, may be easily found from data reported in Appendix A. In the following subsections, the various types of tests and measurements performed are described.

TABLE 4.1

TEST MATRIX

TEST NO.	MIXTURE SERIES/ STRENGTH	TYPE OF TEST	SURFACE FINISH	ABRASION SPEED km/hr	HOUR OF ABRASION	ABRASION FORCE (kN)	IMPACT SEQUENCE
1	I/35 MPa	Abrasion	Textured Surface	3.3	166	13.4	-
2	I/35 MPa	Abrasion	Textured Surface	3.3	166	13.4	-
3*	I/35 MPa	Impact	Non-textured Surface	-	-		A
3*		Impact & Abrasion	Non-textured Surface	3.3	90	13.4	B
4*	III/65 MPa	Impact	Non-textured Surface	-	-		A
4*		Impact & Abrasion	Non-textured Surface	3.3	80	13.4	B

Sequence A: 200 impacts @ 1 m/sec
200 impacts @ 1.3 m/sec
200 impacts @ 1.6 m/sec
200 impacts @ 1.8 m/sec
200 impacts @ 2.0 m/sec

1000 impacts Total

Sequence B: 50 impacts @ 1 m/sec
Repeated 5 times over duration of test, and separated by abrasion periods

* Impact, and impact and abrasion tests were performed on the same specimen.

TABLE 4.2

CONCRETE TEST SPECIMEN BATCH REFERENCE

TEST NO.	CONCRETE TYPE	BATCH DATE
1	I	85-12-12
2	I	85-12-12
3	I	85-12-13
4	III	86-02-11

4.3 Test Description

a) Abrasion Testing

Abrasion testing was performed to establish the effects of continuous lov pressure abrasion on the low-strength concrete samples having textured surfaces.

Testing was performed continuously for a period of 6 to 8 h which was the duration of vear of each ice block. As each block vore out, testing was stopped until a nev block could be mounted; the testing was then continued.

b) Impact Testing

Impact testing was performed to determine the effect of successive impacts on lov- and high-strength concrete specimens, and as a prelude to abrasion testing of concrete subjected to impacts. Table 4.1 describes the sequences for the impact testing. Both concrete specimens used in these tests had a smooth finish.

Slight changes in the test set up vere made in order to accommodate large impacts. The roller bearings were removed and replaced with plain journals to eliminate the possibility of damage to the expensive roller bearings. It was not necessary to conduct impacts under vet conditions; therefore, the water bath was removed.

Impact testing was carried out at five impact speeds ranging from 1 to 2 m/s. The speed was set prior to testing by direct measurements of the slope of the displacement-time trace recorded by an oscillograph. This method was found to be fast and accurate.

A Type I concrete sample was strain gauged to record time histories of strain within the specimen. This was done by using gauges wired in a half bridge on each of the outer rebar, inner rebar and axle as shown in Figure 2.1. These gauge, located in a single plane, were aligned vertically above the axle for testing.

At the beginning of each impact sequence, a series of five impacts were conducted while measurements were made of ram position, acceleration, and strain gauge response during the impact. These data were stored on disk as time histories for future analysis.

The set of 200 impacts was conducted without further data acquisition. Following each set of impacts the ice block was changed in order to provide a uniform surface for impacting, similar to that provided at the beginning of the test. Using this nev ice block a second set of view impacts was conducted with data acquisition to determine any changes in response which had occurred over the period of the test.

c) Sequential Impact/Abrasion Testing

On the completion of the impact testing, an abrasion resistance test was performed on the same concrete samples, together with additional impacts.

The procedure for carrying out the sequential impact/abrasion testing combined the procedures of the impact and abrasion tests. A water bath was used during abrasion testing to avoid ice buildup; however, this had to be emptied during the impact testing. No strain gauge, or acceleration data was acquired during this test.

Impact speeds were limited to 1 m/s during this test in order to simulate the lower range of impact forces which are believed to be more common in the field.

4.4 Measurement Techniques

Measurements taken during this testing program included the surface profile of the concrete specimen, the output from strain gauges mounted on the reinforcing bar of one of the specimens, and the impact speed and acceleration of the ice block.

Measurements of the surface profile were made at intervals of about 25 h of abrasion. These measurements were made using a Linear Variable Differential Transformer (LVDT) mounted on rails permitting it to traverse longitudinally above the specimen. Through a system of locating pins, the profile measuring frame could be remounted accurately above each specimen. This measuring apparatus is shown in Figure 4.1.

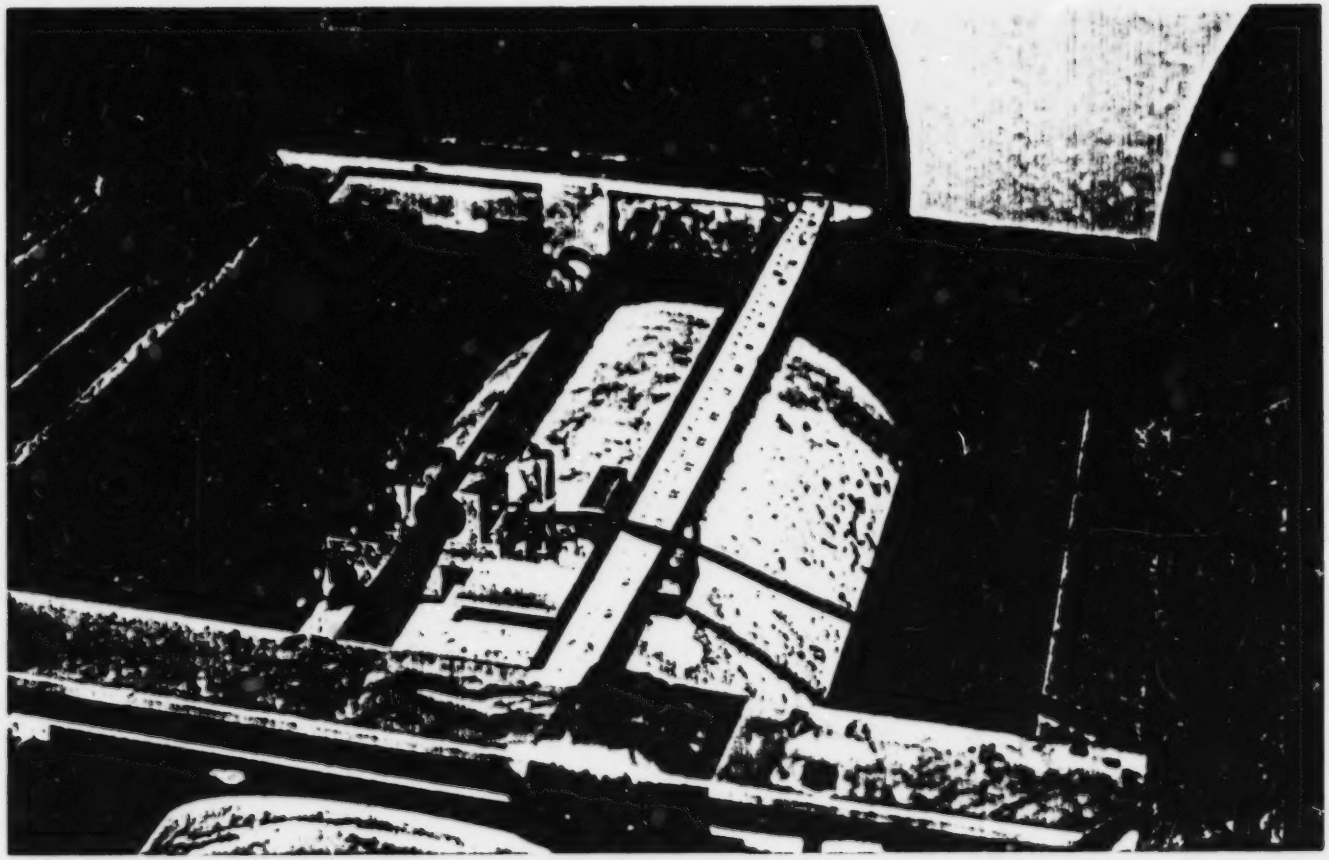
The output from the LVDT was digitized by the microcomputer and recorded on disk for analysis and plotting. Measurements were made a eight locations, at 60 mm intervals along the length of the specimen, starting 40 mm from the driving end. The average radius of the specimen at each measuring location was obtained from the data, measured over two rotations of the specimen. The first and last measurements were made on the unabraded ends of the specimen to provide a reference. Repeatability of measurements made at each measurement location was observed to be about 0.1 mm.

Photographs of the specimens were taken at intervals of about 40 hrs during abrasion testing. A 35 mm camera modified by a bellows lens for close-up photography was used together with flood lighting. This resulted in a very short depth of field, but photographs taken perpendicular to the specimen axis produced good results.

A three phase recording power meter was used to record the power consumed by the electric drive motor during the testing. From the data obtained by this instrument it was possible to measure the relative friction force in effect during the testing. It was also possible to determine the length of time abrasion was carried out on each ice block.

FIGURE 4.1

SURFACE PROFILE MEASURING APPARATUS



5. RESULTS AND DISCUSSIONS

5.1 Results

The results obtained during the present experimental program include:

a) Visual inspection and observation and photographic records of the condition of the concrete at intervals during testing.

b) Abrasion profiles which were taken to quantify the abrasion rate.

c) Strain response of one concrete specimen to ice impact.

d) Other measurements as outlined in Section 4.4.

The results are provided in Appendix B. However, a summary of the qualitative as well as quantitative results of the four test sets are presented below. The original as-cast surface conditions of textured and non-textured specimens are depicted in Figure 2.3 (a) and (b). Figures 5.1 through 5.4 present the surface conditions at the end of each test. The exposure and removal of aggregate below the surface is noted in both textured and non-textured specimens. A complete set of slides documenting the progress of surface deterioration for each specimen is provided as an annex to the report for reference purposes.

Tables 5.1 and 5.2 provide a summary of quantitative measurements made during the program. The deterioration of the surface is expressed in terms of mean and maximum wear and the mean wear rate. The latter is the incremental or interval rate rather than the cumulative mean rate.

The actual profiles of the specimens tested are illustrated in Figure 5.5 and 5.6 for Test Specimens 1 and 2 after 91 hours and 160 hours of abrasion, respectively. Figure 5.7 gives the wear profile measurements along Specimens 3 and 4 after 80 hours of abrasion. It should be noted that Specimens 1 and 2 were textured while Specimens 3 and 4 were non-textured.

FIGURE 5.1

SURFACE CONDITIONS AT THE END OF TEST NO. 1
FOR TEXTURED SURFACES

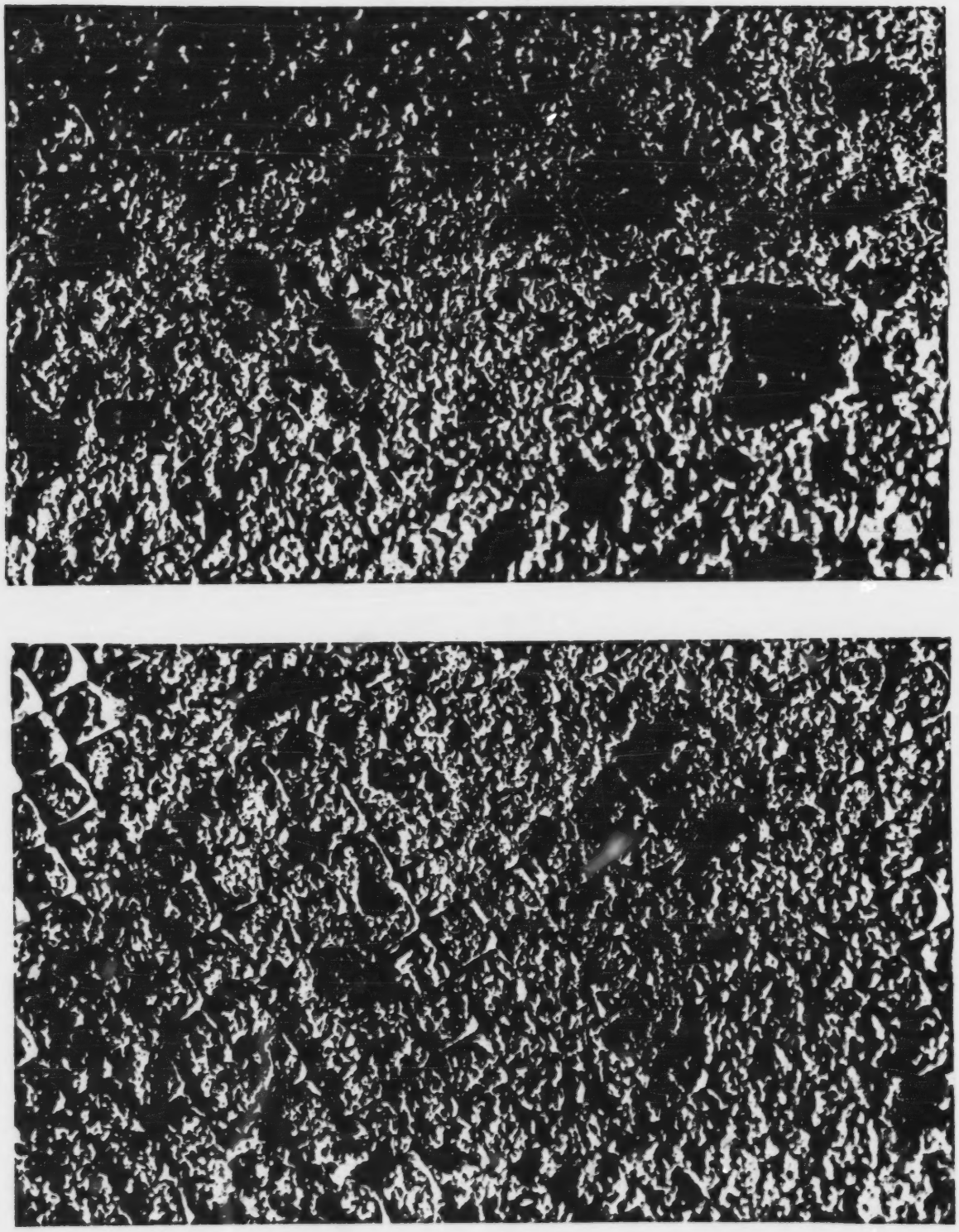


FIGURE 5.2

SURFACE CONDITIONS AT THE END OF TEST NO. 2
FOR TEXTURED SURFACES

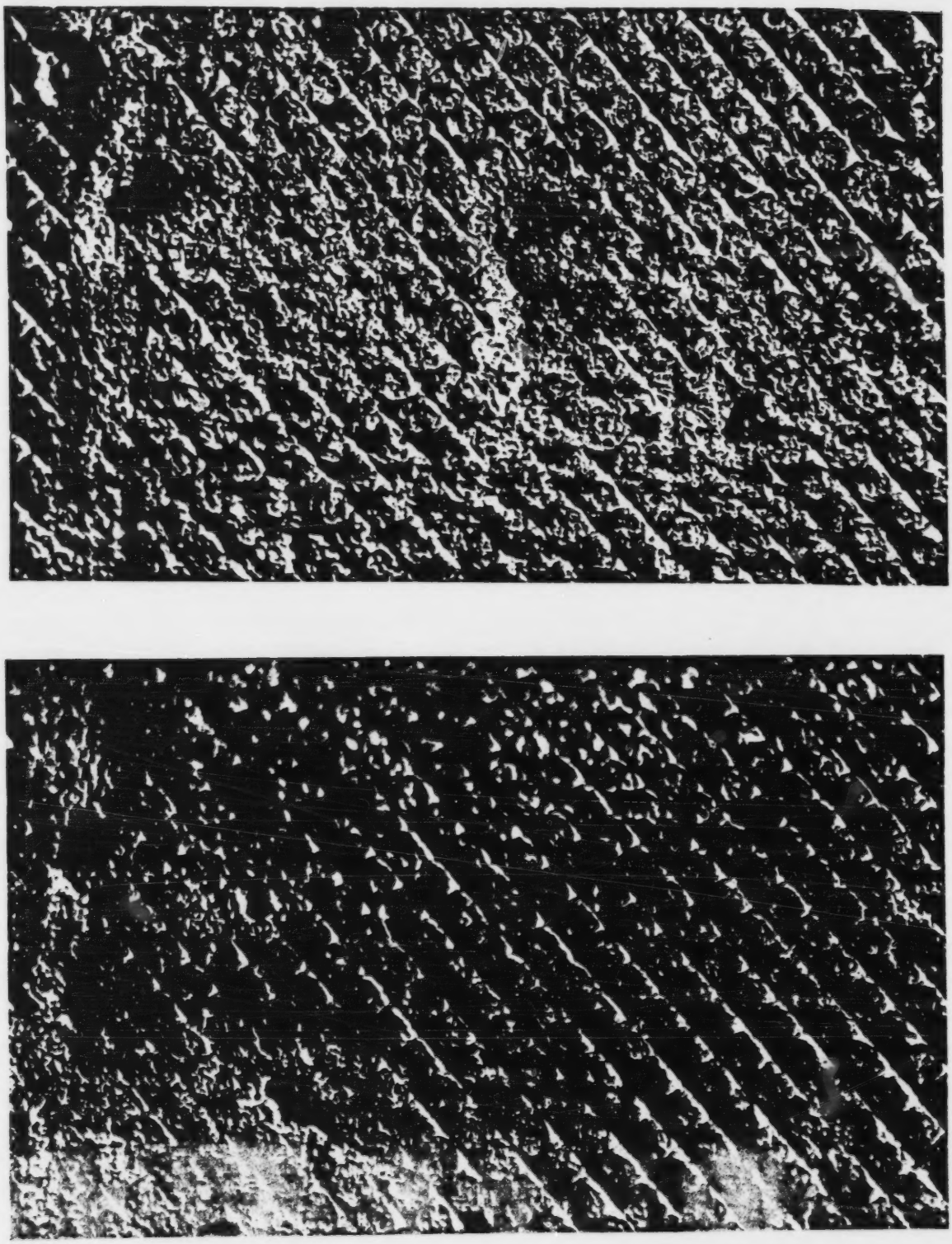


FIGURE 5.3

SURFACE CONDITIONS AT THE END OF TEST NO. 3
FOR NON-TEXTURED SURFACES

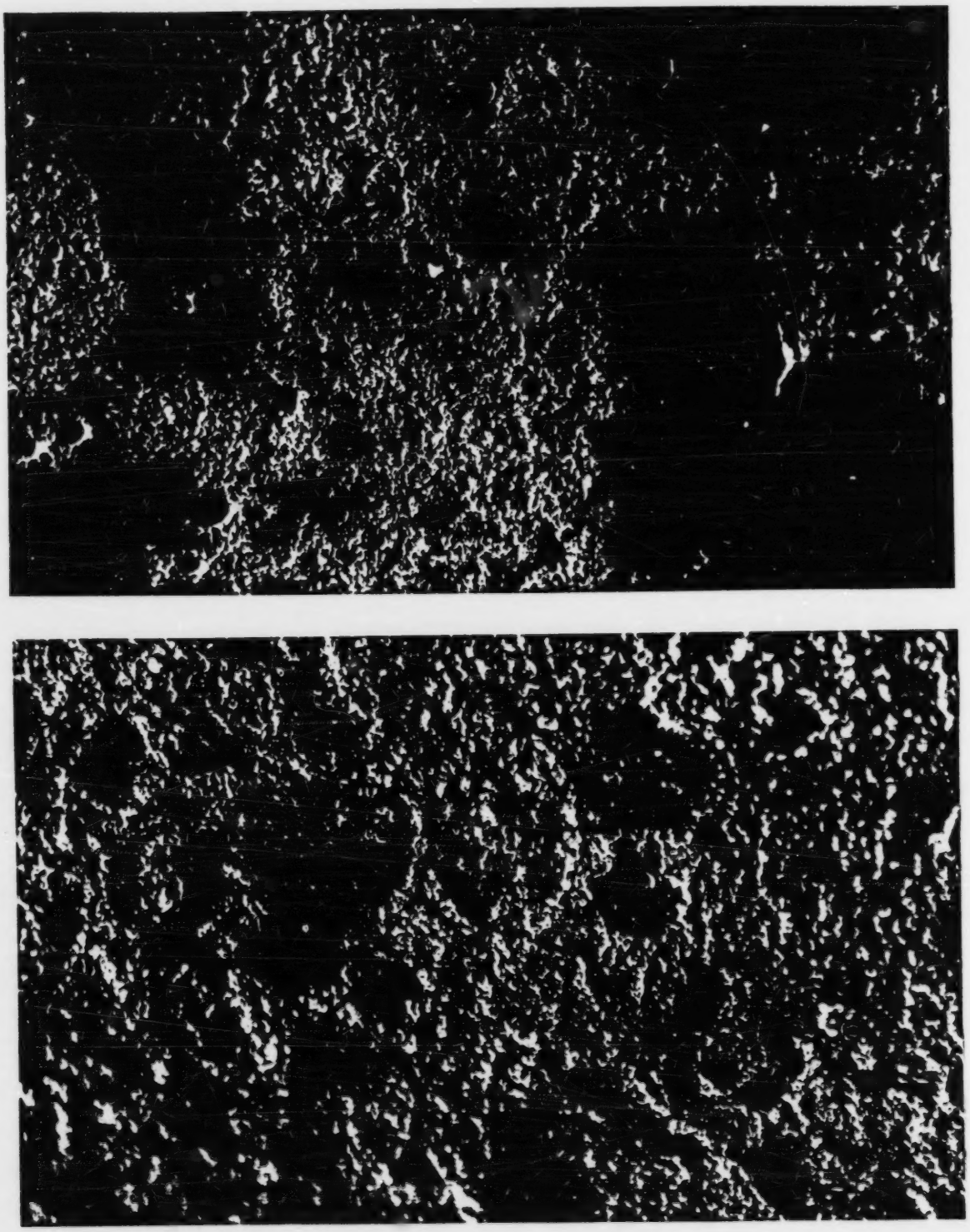


FIGURE 5.4

SURFACE CONDITIONS AT THE END OF TEST NO. 4
FOR NON-TEXTURED SURFACES

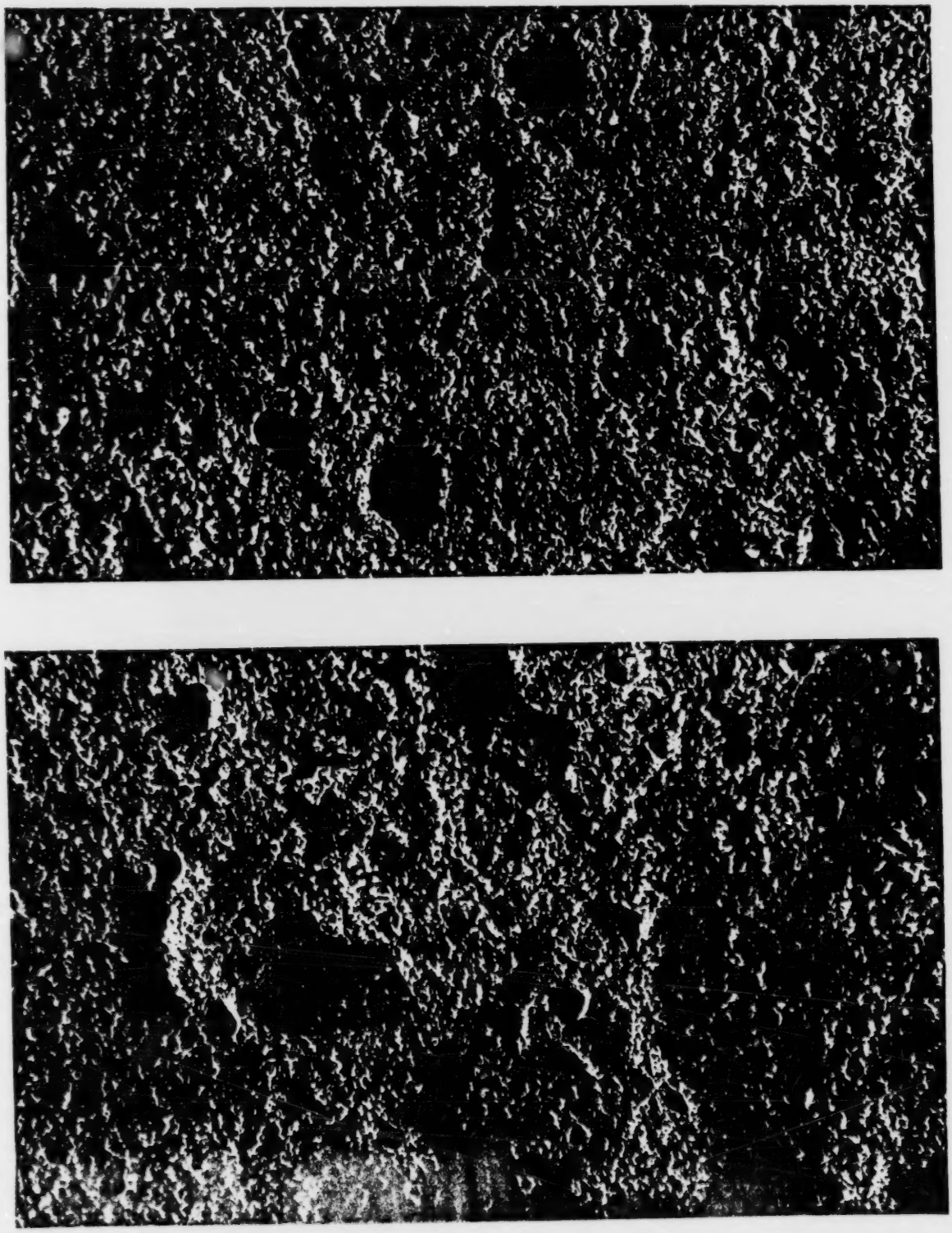


TABLE 5.1 RESULTS OF CONCRETE ABRASION TEST

Hours of Testing	Concrete Mixture Series I*					
	Test 1			Test 2		
	Mean Wear (mm)	Maximum Wear (mm)	Mean Wear Slope (mm/h)	Mean Wear (mm)	Maximum Wear (mm)	Mean Wear Slope (mm/h)
10	0.414	0.545	0.041	0.312	0.502	0.031
25	0.503	0.71	0.006	0.294	0.554	-
66	0.847	1.00	0.008	0.596	0.879	-
91	0.853	1.025	0.0002	0.524	0.751	0.003**
105	0.917	1.036	0.005	0.542	0.693	0.001
127	1.02	1.14	0.005	0.552	0.727	0.0005
166	1.12	1.17	0.003	0.564	0.644	0.0003

* Nominal 28-d compressive strength 35 MPa.

**from 10 h

TABLE 5.2 RESULTS OF COMBINED IMPACT AND ABRASION TESTING

Hours of Testing	Concrete Mixture Series I*			Concrete Mixture Series II**		
	Test 3			Test 4		
	Mean Wear (mm)	Maximum Wear (mm)	Mean Wear Slope (mm/h)	Mean Wear (mm)	Maximum Wear (mm)	Mean Wear Slope (mm/h)
0	0	0	0	0	0	0
25	0.078	0.134	0.0031	0.023	0.059	0.0009
34	0.143	0.313	0.0072	0.088	0.152	0.007
59	0.31	0.375	0.007	0.188	0.256	0.004
80	0.42	0.499	0.005	0.197	0.295	0.0004

* nominal 28-d compressive strength = 35 MPa
**nominal 28-d compressive strength = 65 MPa.

FIGURE 5.5

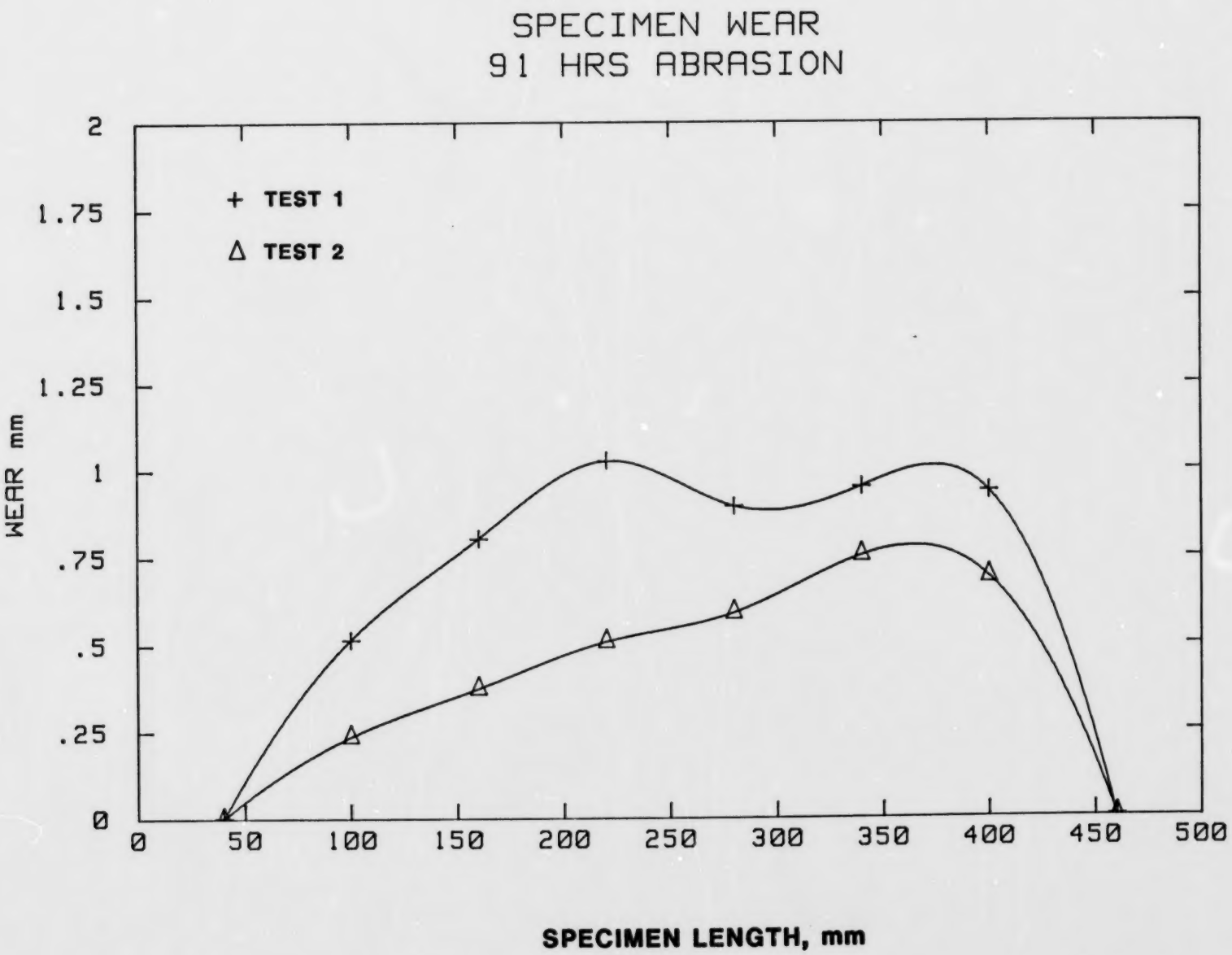

SPECIMEN WEAR
91 HRS ABRASION
+ TEST 1
Δ TEST 2
WEAR mm
2
1.75
1.5
1.25
1
.75
.5
.25
0
0
50
100
150
200
250
300
350
400
450
500
SPECIMEN LENGTH, mm

FIGURE 5.6

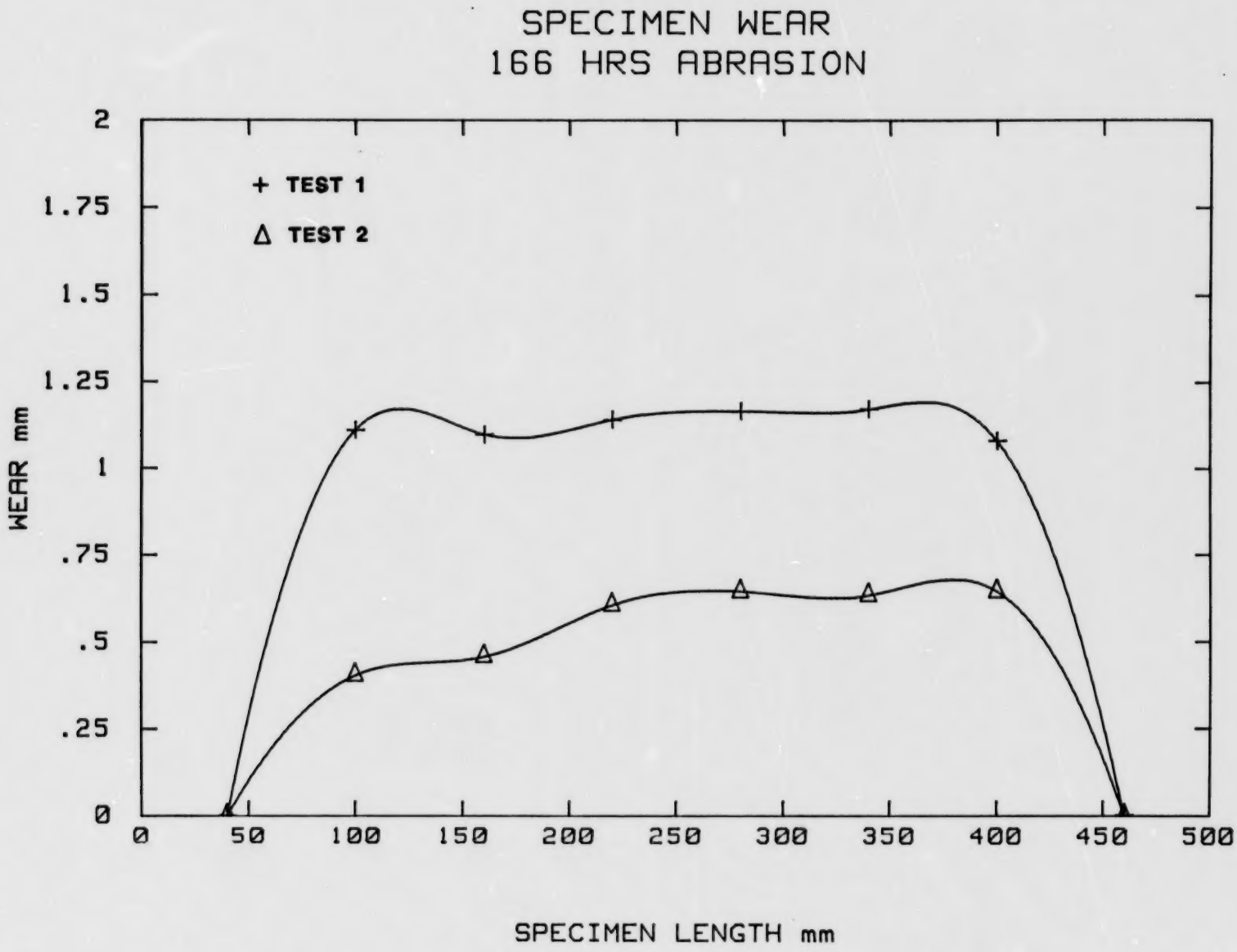
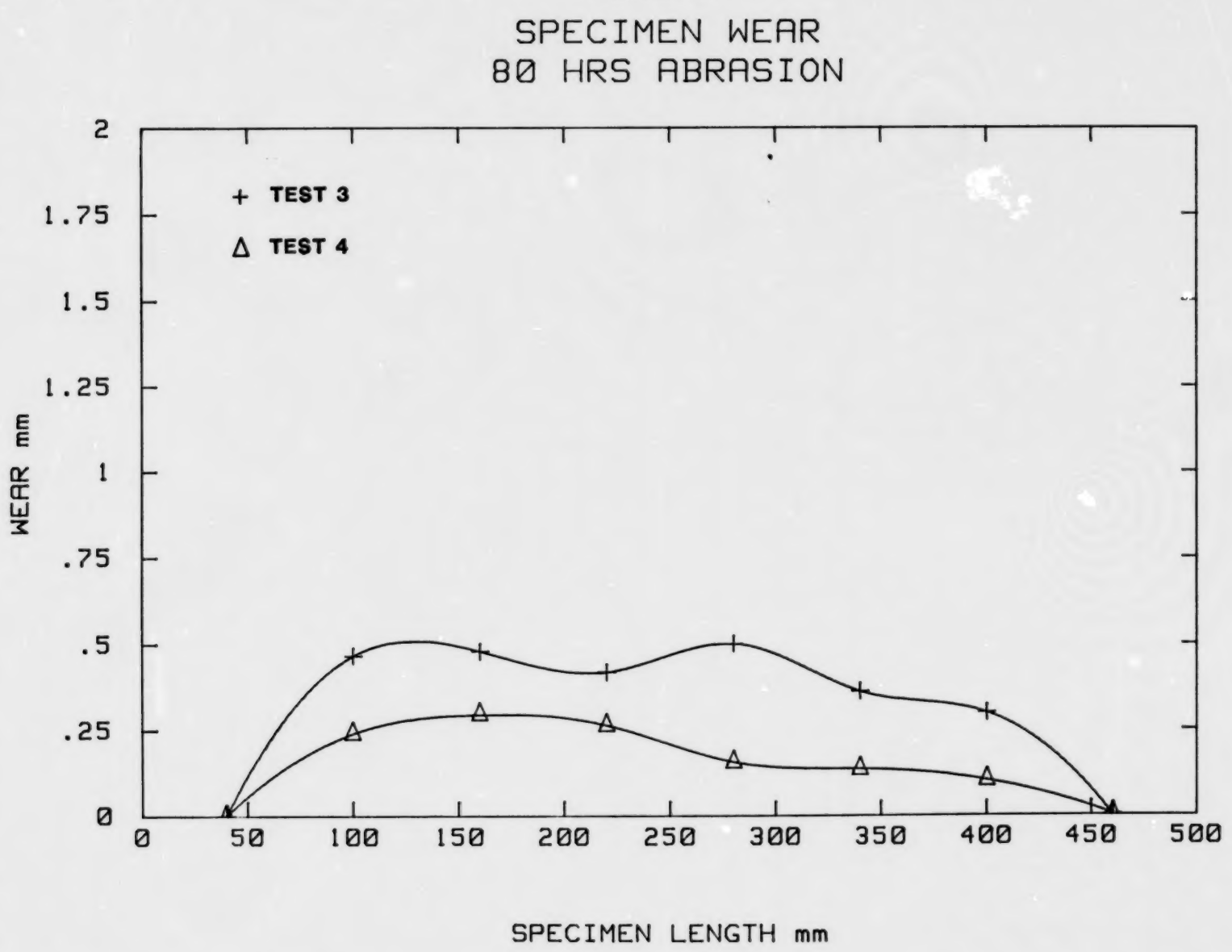

SPECIMEN WEAR
166 HRS ABRASION
+ TEST 1
Δ TEST 2
WEAR mm
2
1.75
1.5
1.25
1
.75
.5
.25
0
0
50
100
150
200
250
300
350
400
450
500
SPECIMEN LENGTH mm

FIGURE 5.7


SPECIMEN WEAR
80 HRS ABRASION
+ TEST 3
Δ TEST 4
WEAR mm
2
1.75
1.5
1.25
1
.75
.5
.25
0
0
50
100
150
200
250
300
350
400
450
500
SPECIMEN LENGTH mm

5.2 Discussion of Results

a) Abrasion Testing Discussion

From the visual and photographic observation of the concrete samples during the test, it appears that specimen 1 (Test 1) mounted on the left hand side of the machine sustained more wear than Specimen 2 (Test 2) mounted on the right hand side. This is also confirmed by the measurements taken by the profilometer. Possible causes of this variation in wear include within-batch casting variations, and changes in the test conditions between the left and the right side of the machine.

This trend of results was also observed in Tests 3 and 4 during which specimen 3 sustained more wear than specimen 4. In this case this may be explained as specimen 4 is of higher strength concrete than specimen 3; however, the wear rates for specimens 1 and 3 are similar and wear rates for specimens 2 and 4 are similar.

Different forces may have been imposed on the two sides of the machine due to the machine geometry with both specimens rotating in the same direction. The friction force caused by the abrasion caused a moment to be exerted on the ice block which was counter balanced by a slight variation between the forces exerted on the two specimens. Using a measured friction factor of 0.06, this force difference was estimated to be 20% of the mean load. This variation could be eliminated by counter rotating the specimens.

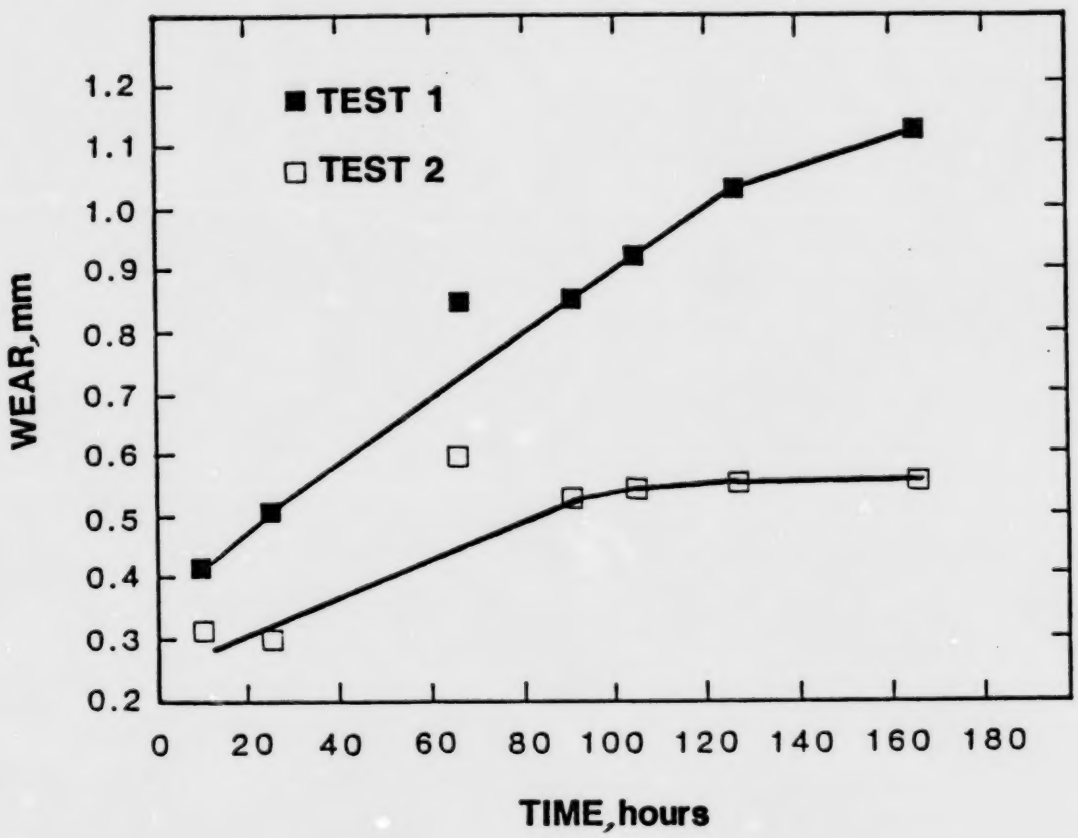
Figure 5.8 illustrates the trend of concrete abrasion for tests No. 1 and 2. The differences between the two tests are obvious and indicate a definite effect of the magnitude of the normal load, or in more precise terms, ice contact pressure. However, in both cases, the observed trend indicates a rapid initial wear becoming slower and constant after ≈90 hours of testing. The final wear rates observed after 166 hours of testing on the two specimens were 0.003 and 0.0003 mm/hr; respectively.

Visual examination of the specimens after testing showed that some areas of the concrete surface had sustained little damage but others had all evidence of the original surface removed. In the worn sections the aggregates were exposed at the surface, and some depressions appeared to have been caused by the aggregate removal.

Approximately 50% of the surface of the specimen in Test 1 was abraded to such an extent that little of the original texture remained while 20% of the surface of the specimen was only lightly damaged, with the remainder falling between these limits. The specimen in Test 2 had suffered much less wear, and the original texture was visible over the entire surface. In general, the appearance of this specimen was similar to that of the specimen in Test 1 after fewer hours of testing.

FIGURE 5.8

ABRASION TEST: MEAN WEAR VERSUS TIME FOR TESTS 1 and 2
(Textured concrete surface)



b) Impact Testing

No visual evidence of external failure in the concrete could be seen during the testing of either normal or high strength concrete specimens. The nature of the ice impacts appeared to change as impact speeds increased with spalling of the ends of the ice block occurring at 1.6 m/s and higher speeds. This could cause higher surface stresses to occur in the concrete due to the localized loading. Extensive ice failure occurred when impacts were conducted at 2 m/s and the ice block was completely destroyed after 100 impacts.

As part of the test plan, one specimen was strain gauged in an attempt to monitor the response of the concrete specimen to ice impact load. The measurements taken during impact testing were examined and no correlation could be made with the impact conditions, and no indication of internal damage could be found.

c) Sequential Impact and Abrasion Testing

The trend of these results was similar to those observed under abrasion testing except that the initial wear rates were lower. This is likely to be a result of the smooth surface finish as opposed to the textured finish of specimens used in the abrasion test. Final wear rates were similar to the results observed during Tests 1 and 2. In Test 3 the specimen had a final wear rate of 0.005 mm/h and in Test 4 wear rate was 0.0004 mm/h. This trend is illustrated in Figure 5.9.

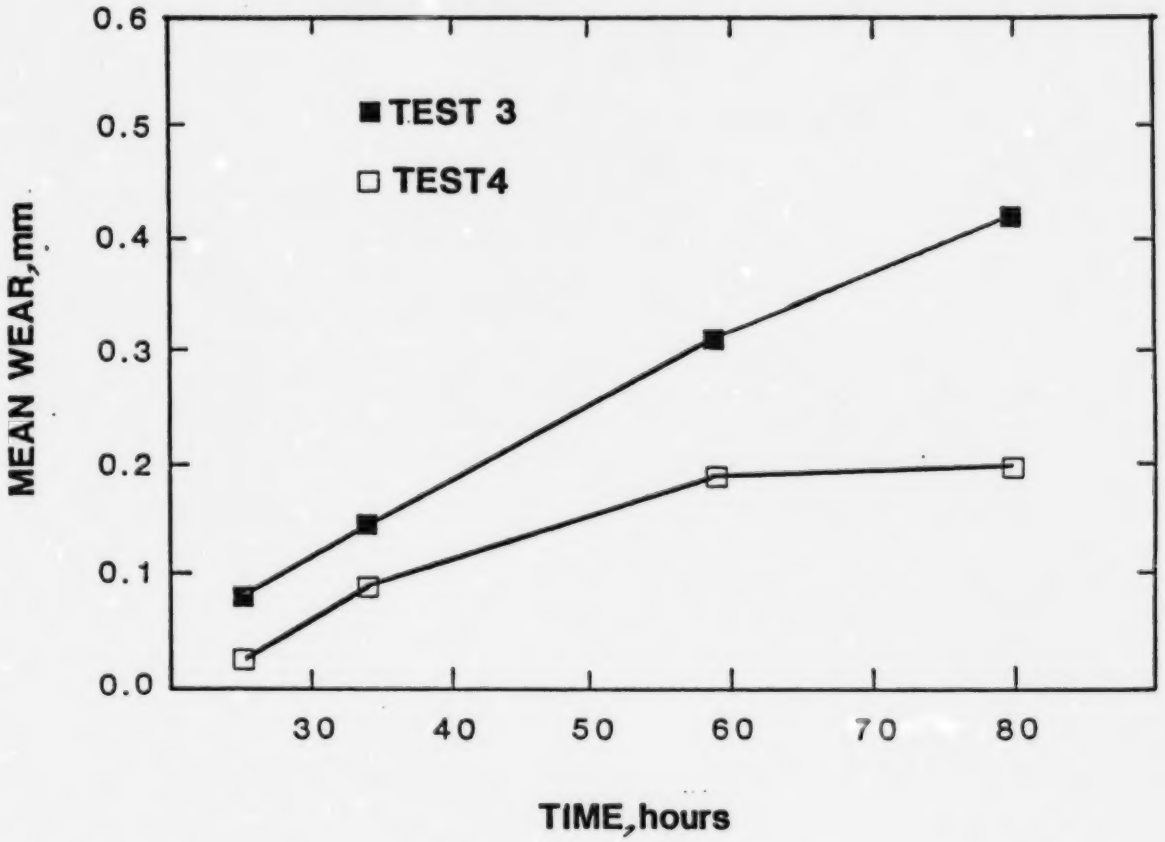
Observations of the manner in which wear took place indicated that initial wear occurred at areas which were located at 45 degrees to the vertical at the bottom of the sample during impacting. This may be an indication of tension cracks occurring in these areas. The wear spread to the areas located at 45° on the top of the sample after 59 hours of testing. The initial failure appeared to be of the surface finish of the concrete; the test duration was not long enough to observe the progress of the failure and deterioration.

No accurate comparison can be made between the wear rates of tests performed on concrete specimens with smooth surface finish with those performed on concrete specimens with textured surface finish until all evidence of the original texture has been removed. A greater amount of material has to be removed from the samples with smooth surface finish for them to show the same amount of wear as the samples with textured surface finish.

The mechanism of ice abrasion appears to be similar for normal and high strength concretes. Within the test duration and considering the unbalanced load distribution between the two test specimens, it is difficult to make any conclusions regarding the differences in abrasion rates.

FIGURE 5.9

IMPACT AND ABRASION TEST: MEAN WEAR VERSUS TIME
FOR TESTS 3 and 4
(Non-Textured concrete surface)



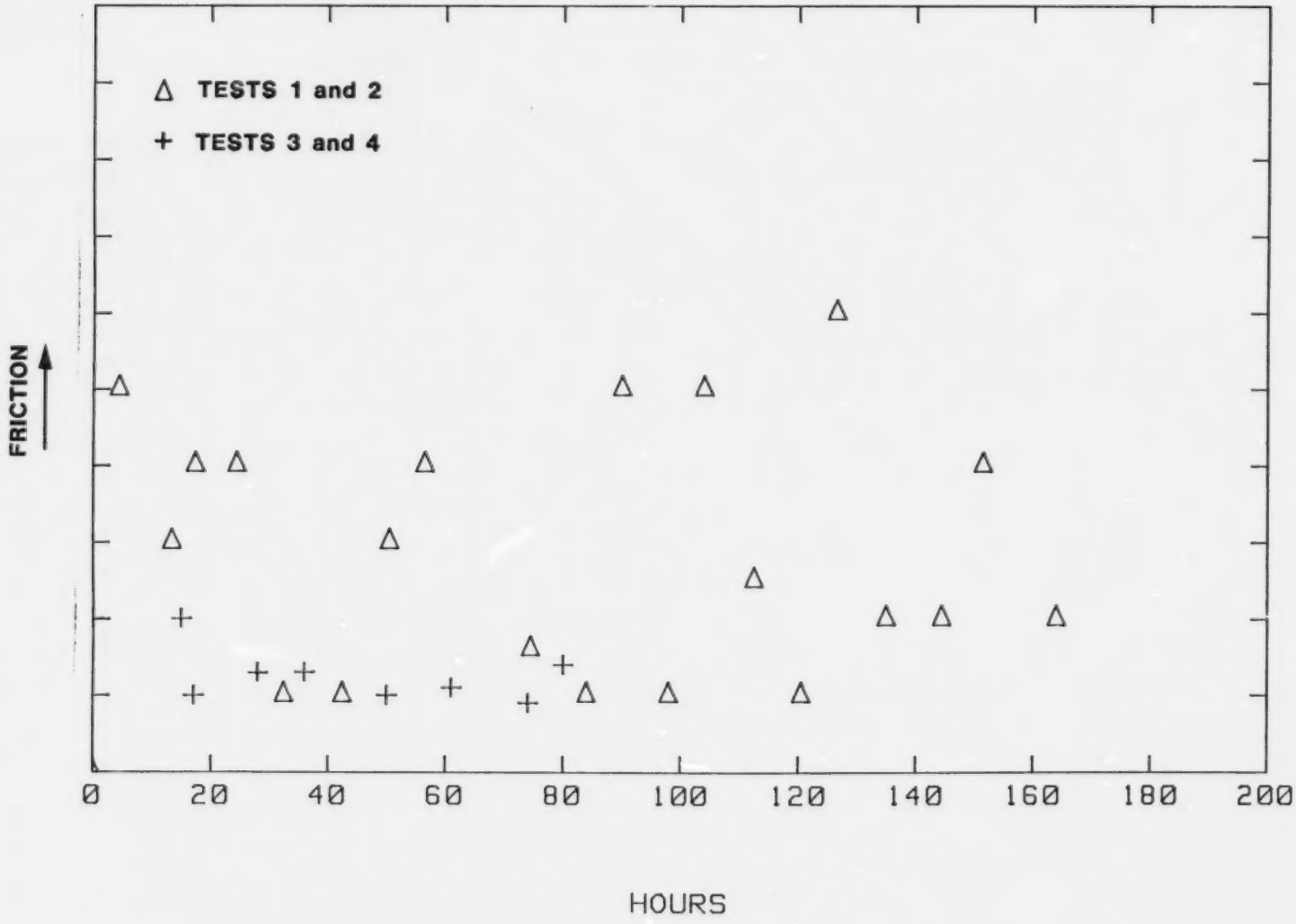
5.3 Friction Measurements

During all abrasion testing an attempt was made to measure the average friction coefficient between the ice and concrete. This measurement was hampered by the lack of a means of accurately calibrating the power meter used for this measurement. The method used to calculate the friction force and friction factor from power measurements is described in Appendix B.

The friction coefficients measured during this test series appeared low. As a result, no absolute values of friction measurements are presented. In Figure 5.10 the relative measurements made during Tests 1 and 2 are compared to those made in Tests 3 and 4.

FIGURE 5.10

TREND OF MEASURED
FRICTION FACTORS



6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

A special test apparatus has been developed and a limited number of tests have been performed to evaluate ice abrasion and impact effects on concrete. Based on the tests performed to date and the data obtained the following conclusions may be drawn.

a) The test apparatus developed in this investigation appears to provide a useful means of studying the effects of abrasion and/or impact by ice against concrete. However, in its present configuration it may subject the concrete specimens to unequal abrasion forces. Modifications are required to the apparatus to remove those unequal forces which are caused by the concrete specimens both rotating in the same direction.

b) Dry abrasion conditions promote the formation of a protective ice layer at an early stage of interaction. This layer is stable and is not removed by intermittent impact by ice. The presence of this layer precludes the direct contact of ice and concrete and no abrasion will take place.

c) Wet abrasion conditions, simulated by continuous concrete specimen wash in a warm bath, indicate that the ice abrades the concrete surface at varying rates depending on the local contact pressure, the surface finish, and the strength of the concrete.

d) The abrasion (wear) rate of the concrete is high at the beginning of interaction, and as the contact progresses it drops to what appears to be a steady state rate. The steady rate observed in Type I normal strength concrete mix after 166 hours is probably of the order of 0.002 - 0.003 mm per hours of active contact. Assuming 3 months of active ice action on a concrete structure, for 10 percent of the time, the annual mean wear rate will be about 0.43 - 0.65 mm/year (17 - 26 mpy). This will be proportionate to the ice activity and duration of ice action.

e) The surface finish of the concrete affects the initial wear rate.

f) The local ice contact pressure on the concrete surface affects the process of abrasion. The wear rate can significantly be reduced if the pressure is reduced, and vice versa.

g) Ice impact at speeds of up to 2 m/s (4 knots) has no immediate effect on the concrete. However, later preferential wear was observed with the progress of abrasion. This may be attributed to the delayed effects of ice impact.

6.2 Recommendations

The following recommendations are made:

a) Before further testing is carried out modifications should be made to the apparatus so that the concrete specimens rotate in opposite directions. This will remove a possible cause of unequal forces on the two specimens.

b) Following the above modifications to the apparatus, testing of concrete to determine its resistance to impact and abrasion by ice should continue so that sufficient data are obtained to reliably indicate the wear rate. This testing should cover the following:

   i) Determine the steady state rate of abrasion following removal of the surface finish for the 35 MPa concrete cast and subjected to initial testing in this investigation.

   ii) Repeat the testing described in i) for the 50 and 65 MPa concretes already cast.

   iii) Determine the effects of freeze-thaw cycling, ice properties and grit embedded ice on the wear rates of concrete subjected to impact and abrasion by ice.

REFERENCES

[1] Nawwar, A.M., Roots, T.J., and Berry, E.E., "Development of Methods for Testing The Resistance of Concrete to Ice Abrasion and Impact", Phase I Report, CANMET, Mineral Sciences Laboratories, July 31, 1985.

APPENDIX A

CONCRETE MIX DESIGN, PROPERTIES AND PREPARATION OF SPECIMENS

CONCRETE LABORATORY LTD

FINAL REPORT

RESISTANCE OF CONCRETE TO ABRASION AND IMPACT BY ICE UNDER OFFSHORE AND ARCTIC CONDITIONS

MIX DESIGN, CONCRETE PROPERTIES AND PREPARATION OF SPECIMEN FOR ABRASION TESTING

SUBMITTED TO ARTEC CANADA LTD

AS PART OF DSS CONTRACT 15SQ 23440-3

QUALITY CONTROL - MATERIALS TESTING
3420 East, St-Joseph blvd., MONTREAL, Qc H1X 1W6
Tel: (514) 255-0613, Telex 055-62366

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4. Task 8: "Preparation of Tests Specimen"

5. Results of Tests on the Physical Properties of the Aggregates

6. Results of Tests on the Concrete

7. Appendix A - Photographs

Resistance of Concrete to Abrasion and Impact by Ice Under Offshore and Arctic Conditions

1. Objective

In the scope of the program "Resistance of Concrete to Abrasion and Impact by Ice", the present report covers the preparation of the specimen for the four types of concrete to be tested.

The concrete was tested for certain of its physical properties and the results are given in this report along with the characteristics of the fresh concrete.

2. Work Schedule

Laboratoire de Béton Ltée was involved in two of the ten tasks of the program:

- Task 3: "Design of Concrete Formulae"
- Task 8: "Preparation of Concrete Specimen"

Task 3 was originally carried out on March 29 and 30, 1984 with compressive strength tests continuing to 28 days later. Then a change in the program required another series of tests from January 14 to February 6, 1986.

The work schedule for task 8 is shown on table 1.

...2

TABLE 1

Task 8

SCHEDULE

Type of Concrete	Specimen n°	Date of Casting	Date of Shipping
1	1	85-12-10	86-01-14
	2	85-12-11	86-01-14
	3	85-12-12	86-01-14
	4	85-12-13	86-01-14
2	5	86-01-21	86-02-25
	6	86-01-22	86-02-25
	7	86-01-23	86-02-25
3	8	86-02-10	86-03-19
	9	86-02-11	86-03-19
	10	86-02-12	86-03-19
4	11	86-02-13	86-03-19
	12	86-02-14	86-03-19

3. Overview of Task 3

3.1 Original Program

The objective of task 3 was to design concrete of type 1 (35 MPa), type 2 (50 MPa) and type 3 (65 MPa). The task was carried out on March 29 and 30, 1984 and the results were transmitted in our report n° 01B (0785).

The trial mixes were performed on the type 2 and type 3 concretes as required except that no fly ash was available at the time and the 65 MPa concrete mix was designed and trial mixes were carried out without it.

3.2 Supplemental Program

During the performance of task 8, two new elements arose necessitating the design of two additional mixes.

Fly ash became available and the type 3, 65 MPa concrete, had to be re-designed considering it's incorporation in the mix.

The number of batches of type 2 and type 3 concrete to be prepared was reduced from four to three to add two batches of type 4 concrete (65 MPa with lightweight aggregates) to the program.

The results of these additionnal tests are given in our report 02B (0386).

4. Task 8: "Preparation of Tests Specimen"

Concrete mixes for all types of concrete were prepared in 0,15 m³ batches, using mix design formulae shown in table 2.

All materials were pre-weighed and placed in sealed bags. Before mixing, water content of the aggregates was measured and all materials were re-weighed.

In the case of the lightweight concrete the aggregates were soaken for a period of 24 hours before using.

The materials were batched according to CSA, CAN3-A23.2 method 2C, paragraph 4.2 (d) and mixed according to paragraph 4.3.

Concrete was cast in steel molds in which a steel shaft and reinforcing steel (photo 1) were secured by means of a hole at the bottom of the mold and a steel collar above the mold (photo 2).

Two types of plastic lining were installed in the molds to simulate smooth (photo 3) and rough (photo 4) surface textures.

All joints in the mold were sealed with a caulking (photo 5) to insure uniformity of the surface (photo 6) and loss of paste.

Concrete was placed in 15 cm layers and each layer-vibrated with a 20 mm diameter internal vibrator. After vibration of each layer the mold was struck with a hammer around its outside circular surface to evacuate air bubles on the inside surface.

After 24 hours the concrete specimen were stripped of the mold, placed in the curing room, at 23°C and 100% relative humidity (according to CSA CAN3-A23.2-3C) for 28 days after which they were shipped to Arctecs laboratory.

From each batch two 50 cm X 30 cm diameter specimen were cast one of each texture for abrasion and impact testing and twelve 30 cm X 15 cm diameter 2 specimen for compressive strength testing.

TABLE 2

Basic Mix Formulae
(as determined in Task 3)

Type of Concrete	1	2	3	4
Compressive strength, MPa	35	50	65	65
Nominal size coarse aggregate, mm	20 mm			
Type of aggregate	normal weight			lightweight
Quantities				
Cement, kg	380	380	420	500
Water, kg	170	101	137	157
Coarse aggregate, kg	1115	1115	1115	650
Sand, kg	620	805	598	549
Fly ash, kg			63	75
Microsilica, kg			25	30
Mighty 150, l		5,7	6,3	10
Protex AES, ml		555	500	600
W/Cement	0.447	0.267	0.326	0.314
W/Cementious			0.270	0.270
Slump, mm	75			
Air Content, %	6%			

5. Physical Properties of Aggregates

5.1 Normal Weight Coarse Aggregates (Black River Quarry)

Specific Gravity: 2.67

Unit Weight: 1613 kg/m³

Absorption: 0.93%

5.2 Lightweight Coarse Aggregates (New Brunswick)

Specific Gravity: 1.70

Unit Weight: 960 kg/m³

Absorption: 3.2%

5.3 Normal Weight Fine Aggregates (Region of Joliette)

Specific Gravity: 2.69

Absorption: 0.80%

Fineness Modulus: 2.56

5.4 Sieve Analysis of Sand

Sieve Size	% Passing	CSA Specification % Passing
10	100	100
5	94	90-100
2,5	86	80-100
1,25	76	50-90
630	57	29-65
315	25	10-35
160	6	2-10
80	1,2	0-3

5.5 Sieve Analysis of Normal Weight Coarse Aggregate

Sieve Size	% Passing	CSA Specifications % Passing
28 mm	100	100
20 mm	94	90-100
14 mm	67	
10 mm	40	25-60
5 mm	6	0-10
2,5 mm	0,4	0-5

5.6 Sieve Analysis of lightweight Coarse Aggregate

Sieve Size	% Passing	ASTM Specifications % Passing
25 mm		100
19 mm	100	90-100
12,5 mm	90	
9,5	53	10-50
4,75	3	0-15
2,36	0,5	

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6. Results of Tests on the Concrete

TYPE 1 CONCRETE

Date of casting	:	85-12-10	85-12-11	85-12-12	85-12-13
FORMULA (kg/m³)					
Cement	:	424	419	420	421
Water	:	160	164	159	161
Coarse agg. 20 mm	:	399	395	395	396
Coarse agg. 14 mm	:	399	395	395	396
Coarse agg. 10 mm	:	339	335	336	336
Sand	:	629	623	623	624
Air agent (ml)	:	25	28	43	32
W/C		0,377	0,390	0,379	0,382
RESULTS					
Slump (mm)	:	85	95	85	90
Air content (%)	:	4,5	5,4	5,4	5,1
Temperature (°C)	:	20	19	19	19
Unit weight (kg/m³)					
Theoretical	:	2350	2331	2328	2334
Fresh	:	2316	2337	2372	2339
28 days	:	2324	2337	2292	2286
Compressive strength, MPa					
7 days	:	32,2	27,6	30,2	28,8
		32,2	27,8	31,5	30,0
		31,5	28,0	31,7	30,0
28 days	:	42,7	36,3	38,0	38,3
		41,1	39,7	39,3	39,5
		39,0	38,3	36,6	37,3
90 days	:	49,3	43,2	47,1	46,1
		50,7	43,2	48,0	47,1
		50,7	43,9	45,1	46,8
120 days	:	50,7	44,4	47,1	47,1
		50,8	45,1	48,8	47,3
		50,8	43,7	48,0	46,7
Modulus of elasticity, MPa X 10^6					
120 days	:	5,04		5,16	4,22
Poisson's ratio					
120 days	:	0,23		0,27	0,20

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TYPE 2 CONCRETE

Date of casting	86-01-21	86-01-21	86-01-23
FORMULA (kg/m³)			
Cement	416	415	421
Water	125	125	126
Coarse agg. 20 mm	381	381	386
Coarse agg. 14 mm	381	381	386
Coarse agg. 10 mm	322	321	326
Sand	737	737	748
Air agent (ml)	50	50	50
Superplastisizer(1)	9,5	9,5	9,5
W/C	0,3004	0,3012	0,2993
RESULTS			
Slump (mm)	100	110	65
Air content (%)	6,4	6,5	5,0
Temperature (°C)	18	18	17
Unit weight (kg/m³)			
Theoretical	2362	2360	2393
Fresh	2240	2240	2310
28 days	2315	2337	2373
Compressive strength, MPa			
7 days	46,3	50,0	56,1
	43,9	49,7	56,1
	48,1	50,0	56,1
28 days	58,6	60,0	62,4
	58,4	59,4	63,0
	50,0 *	61,4	63,4
90 days	62,9	64,7	74,4
	63,9	67,3	75,6
	66,6	68,3	74,4
120 days	67,6	68,0	75,9
	67,8	69,8	75,4
	70,0	71,7	74,9
Modulus of elasticity, MPa X 10^6			
90 days	4,41	4,60	4,97
120 days	4,93	4,61	4,91
Poisson's ratio			
90 days	0,23	0,23	0,22
120 days	0,25	0,23	0,15

* Not to be considered

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TYPE 3 CONCRETE

Date of casting	86-02-10	86-02-11	86-02-12
FORMULA (kg/m³)			
Cement	415	420	416
Water	135	134	133
Coarse agg. 20 mm	384	390	387
Coarse agg. 14 mm	384	390	387
Coarse agg. 10 mm	330	335	332
Sand	590	598	593
Fly ash	62	63	63
Microsilica	25	25	25
Air agent (ml)	75	60	60
Superplastisizer(l)	6,3	5,2	5,4
W/C	0,33	0,32	0,32
W/C + M + F	0,27	0,26	0,26
RESULTS			
Slump (mm)	110	100	110
Air content (%)	7,0	5,5	6,4
Temperature (°C)	18	17	17
Unit weight (kg/m³)			
Theoretical	2325	2355	2336
Fresh	2252	2356	2313
28 days	2261	2331	2361
Compressive strength, MPa			
7 days	41,5	54,5	54,4
	41,5	54,5	53,9
	45,1	53,6	54,6
28 days	58,1	65,8	66,4
	59,1	66,6	67,1
	57,1	67,6	67,1
90 days	58,6	66,0	68,8
	58,6	70,8	70,8
	59,0	68,1	68,8
120 days	59,8	69,5	69,8
	62,0	72,2	69,9
	60,9	74,2	
Modulus of elasticity, MPa X 10^6			
90 days		4,59	4,79
120 days		4,08	5,31
Poisson's ratio			
90 days		0,24	0,25
120 days		0,23	0,55

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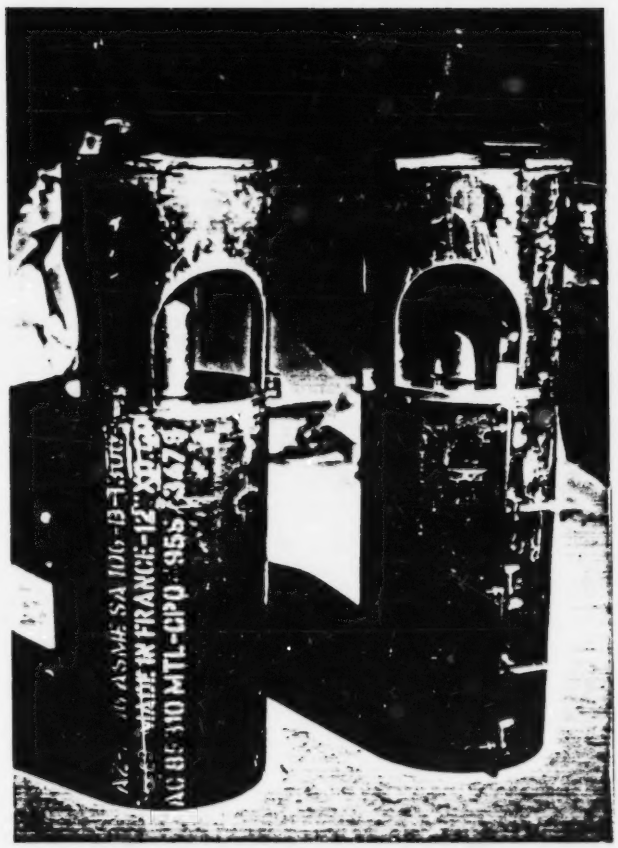
TYPE 4 CONCRETE

Date of casting	:	86-02-13	86-02-14
FORMULA (kg/m³)			
Cement	:	500	500
Water	:	167	167
Coarse agg. 20 mm	:	260	260
Coarse agg. 14 mm	:	130	130
Coarse agg. 10 mm	:	260	260
Sand	:	549	549
Fly ash	:	75	75
Microsilica	:	30	30
Air agent (ml)	:	60	96
Superplastisizer(l)	:	10	9,5
W/C		0,334	0,334
W/C + M + F		0,26	0,26
RESULTS			
Slump (mm)	:	80	80
Air content,			
pressure method(%)	:	4,9	5,7
volumetric method(%)	:	7,5	9,0
Temperature (°C)	:	16	16
Unit weight (kg/m³)			
Theoretical	:	1971	1971
Fresh	:	1959	1962
28 days	:	1894	1899
Compressive strength, MPa			
7 days	:	58,0	54,1
		57,1	55,1
		56,6	54,9
28 days	:	62,1	63,8
		66,1	63,0
		63,8	64,8
90 days	:	64,4	64,8
		63,6	63,4
		63,7	67,3
120 days	:	64,4	66,1
		63,8	65,4
		63,7	67,2
Modulus of elasticity, MPa X 10^6			
90 days	:	4,03	3,71
120 days	:	3,38	3,51
Poisson's ratio			
90 days	:	0,24	0,21
120 days	:	0,22	0,22

PHOTO NO 1

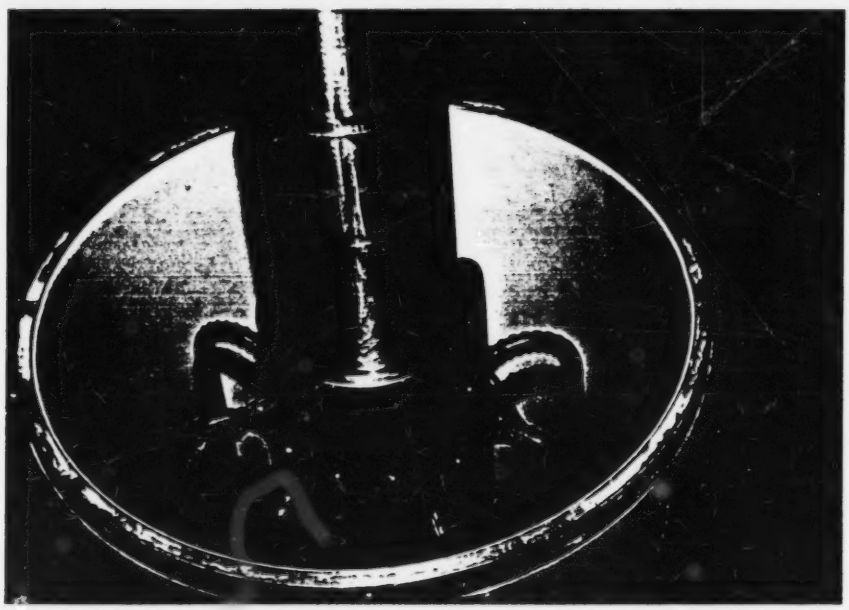
STEEL SHAFT AND REINFORCING STEEL

PHOTO NO 2



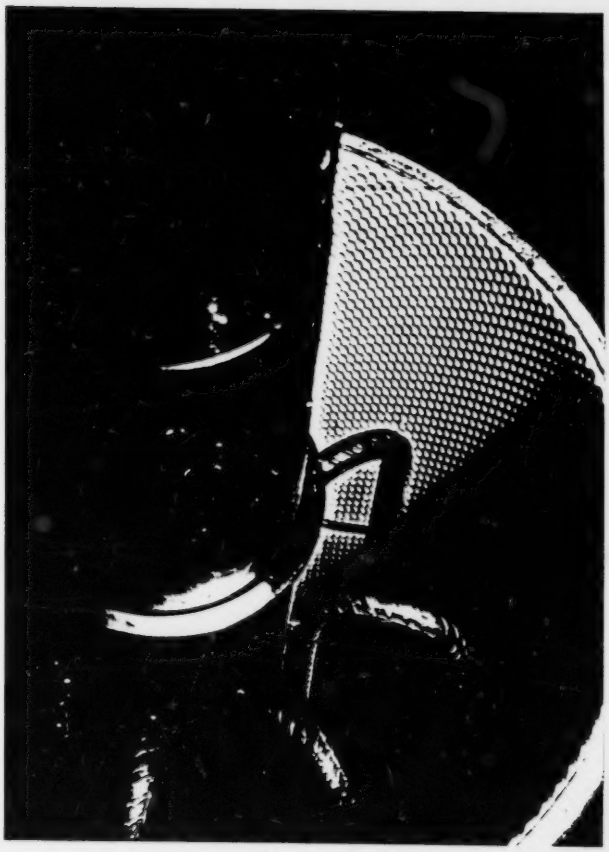
MOLDS WITH SHAFT SECURING DEVICE

PHOTO NO 3



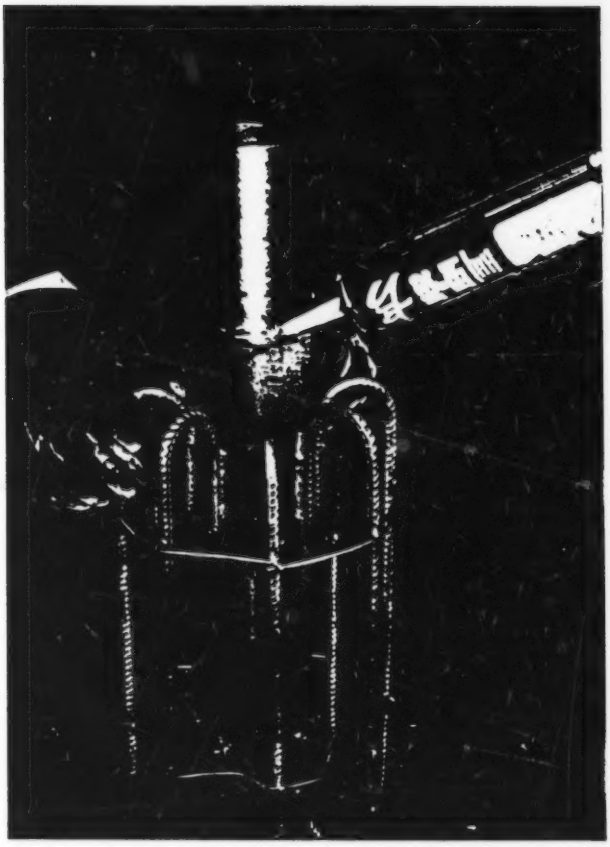
SMOOTH TEXTURE PLASTIC LINER

PHOTO NO 4



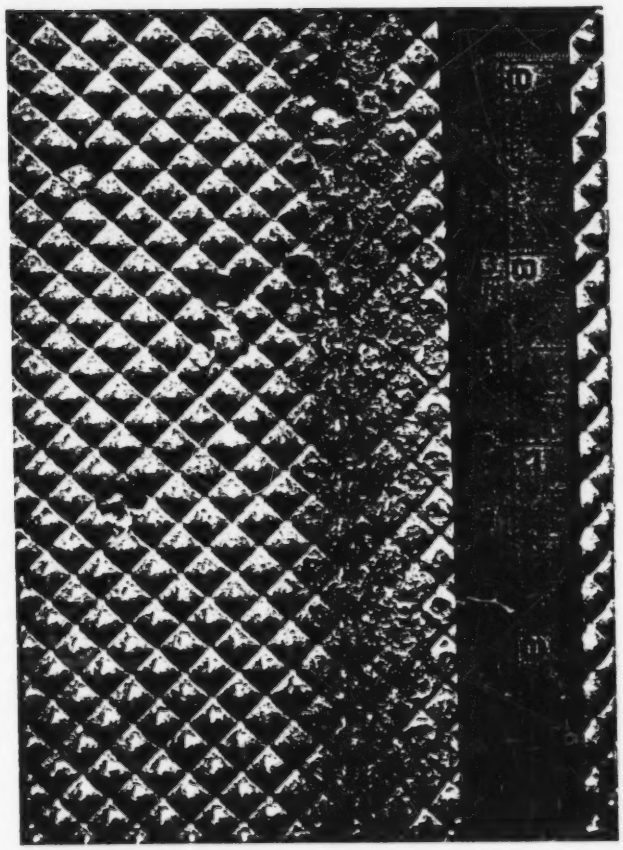
ROUGH TEXTURE PLASTIC LINER

PHOTO NO 5



APPLICATION OF SEALER ON SHAFT

PHOTO NO 6



TEXTURE AT MOLD VERTICAL JOINT

APPENDIX B

DETAILED TEST RESULTS

B.1 Wear Profile Measurements

The test results reported in this appendix have been obtained under the following conditions:

- Air temperature was maintained constant at -10°C for all tests. The variation in air temperature was within 1°C.
- Ice blocks were placed in the test chamber for at least 24 hours to stabilize at test temperature. After fitting the blocks in the ice retainer they were allowed to freeze for at least 12 hours at -10°C before testing.
- The water bath temperature was maintained in the range between 2 and 5°C during all abrasion tests.
- The wear profiles were later measured and averaged over the length of the specimen.

B.2 Power Measurements

The power measurements were printed on intervals during the testing. The following tables list the measurements and inferred friction factors. The method of calculation of friction factor from measured power is given below.

FRICTION FACTOR CALCULATION

Specimen Diameter 0.3 m

Range of Friction calculated assuming:

1. All transmission losses are accounted for by subtracting the no-load condition power from the full load power.

SPEED = 50.26 RPM X 1/60 X 0.3 M X π = 0.789 m/sec

$$\therefore \text{FORCE [KN]} = \frac{\text{POWER}}{\text{SPEED}} = \frac{\text{POWER [kW]}}{0.789}$$

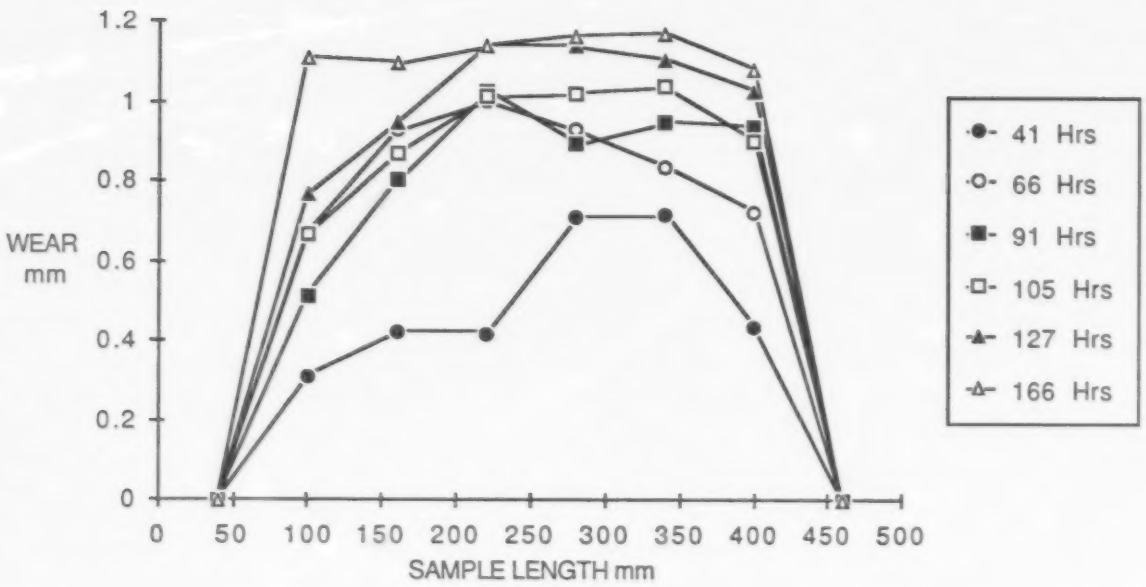
NORMAL FORCE = (1900 psi) x 6.89 = 13.09 MPa (Hyd press)

$$(13.09 \text{ Mpa})\ (\pi \text{ in}^2)\ (0.0254)^2 = 26.5 \text{ kN}$$

$$\therefore \text{FRICTION FACTOR} = \frac{\text{POWER [kW]}}{[0.789]\ [26.5]} = \frac{\text{POWER [kW]}}{20.91}$$

TABLE B.1

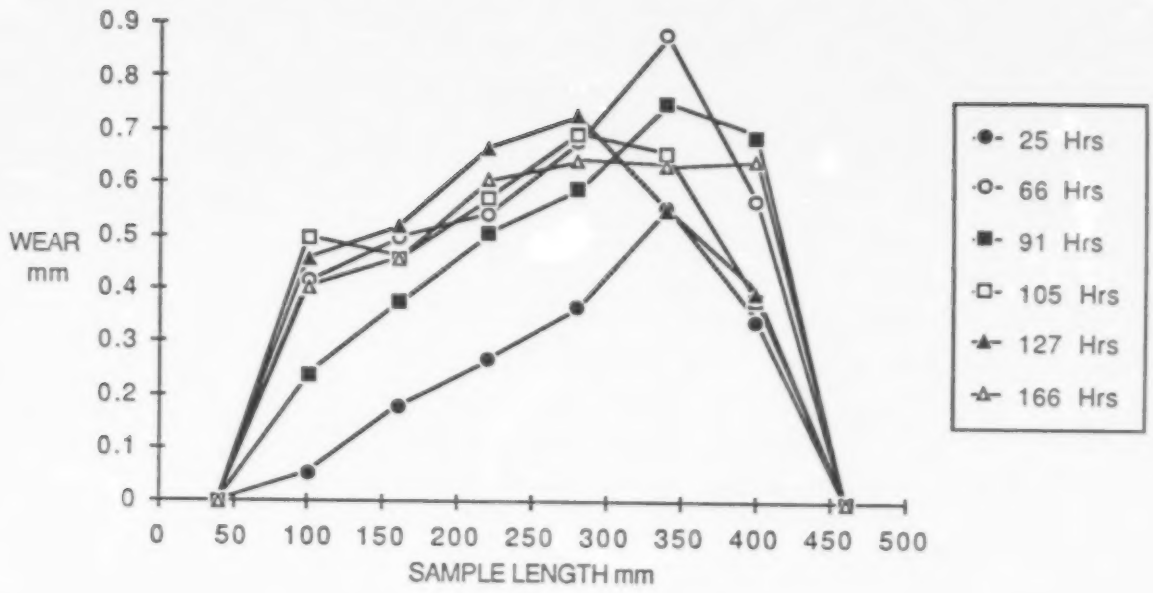
ABRASION TEST 1



SAMPLE LENGTH mm	MEASURED WEAR mm					
	41 Hrs	66 Hrs	91 Hrs	105 Hrs	127 Hrs	166 Hrs
40	0	0	0	0	0	0
100	0.31	0.67	0.515	0.666	0.766	1.11
160	0.423	0.927	0.802	0.871	0.949	1.096
220	0.42	1	1.025	1.011	1.141	1.14
280	0.712	0.927	0.892	1.02	1.136	1.164
340	0.717	0.837	0.949	1.036	1.105	1.17
400	0.433	0.723	0.936	0.9	1.023	1.079
460	0	0	0	0	0	0

TABLE B.2

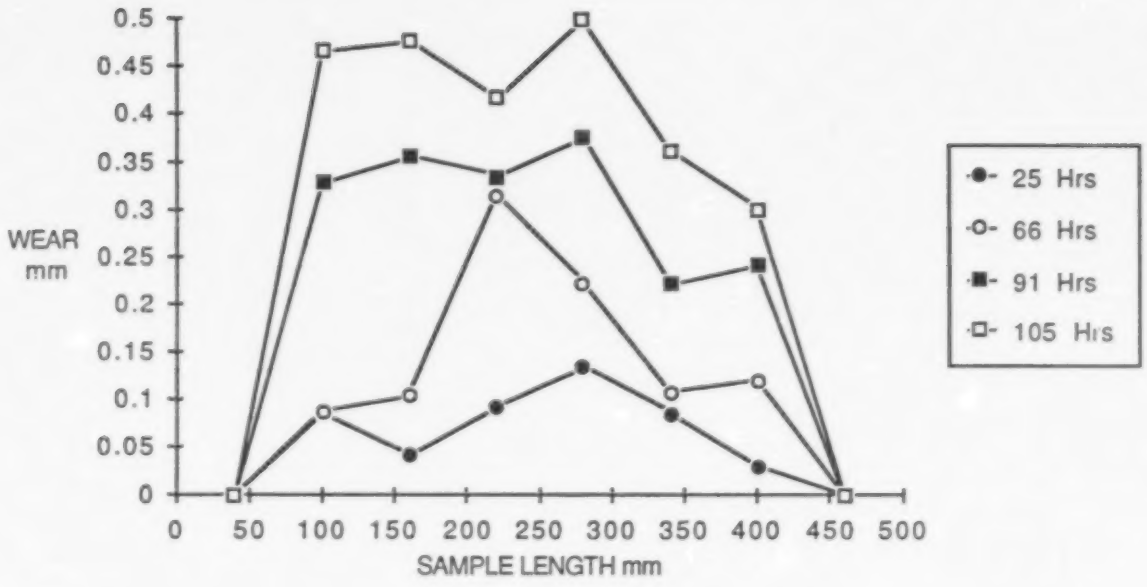
ABRASION TEST 2



SAMPLE LENGTH mm	MEASURED WEAR mm					
	25 Hrs	66 Hrs	91 Hrs	105 Hrs	127 Hrs	166 Hrs
40	0	0	0	0	0	0
100	0.054	0.415	0.237	0.497	0.457	0.404
160	0.181	0.496	0.374	0.457	0.519	0.458
220	0.269	0.541	0.507	0.572	0.667	0.606
280	0.366	0.678	0.588	0.693	0.727	0.644
340	0.554	0.879	0.751	0.655	0.55	0.633
400	0.341	0.569	0.689	0.38	0.394	0.644
460	0	0	0	0	0	

TABLE B.3

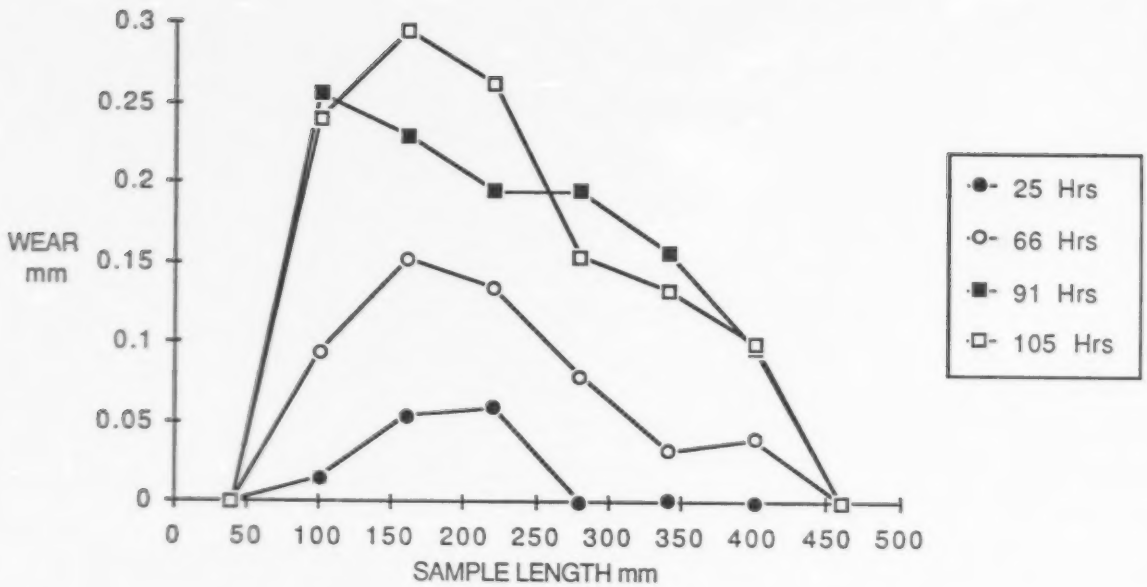
ABRASION TEST 3



SAMPLE LENGTH mm	MEASURED WEAR mm					
	25 Hrs	34 Hrs	59 Hrs	81 Hrs		
40	0	0	0	0		
100	0.085	0.088	0.327	0.466		
160	0.042	0.105	0.356	0.478		
220	0.092	0.313	0.334	0.417		
280	0.134	0.222	0.375	0.499		
340	0.085	0.107	0.22	0.36		
400	0.03	0.12	0.24	0.298		
460	0	0	0	0		

TABLE B.4

ABRASION TEST 4



SAMPLE LENGTH mm	MEASURED WEAR mm					
	25 Hrs	34 Hrs	59 Hrs	81 Hrs		
40	0	0	0	0		
100	0.015	0.094	0.256	0.24		
160	0.054	0.152	0.23	0.295		
220	0.059	0.134	0.195	0.262		
280	0	0.079	0.195	0.154		
340	0.0009	0.032	0.157	0.133		
400	0	0.04	0.097	0.1		
460	0	0	0	0		

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a member of the Arctec Group

May 21, 1987.
Our File: 1585C

Dr. V.M. Malhotra,
Head, Construction Materials Section,
CANMET, Energy, Mines and Resources, Canada,
555 Booth Street, Ottawa,
Ontario.
K1A 0E4

Dear Dr. Malhotra:

Re: Determination of the Resistance of Concrete to Abrasion and Impact by Ice Under Offshore and Arctic Conditions
DSS NO. 23SQ.23440-4-9173

Our final report was sent to you yesterday and it included an original one-sided copy. In the appendices the original photos were not included but I have found an extra set and I am forwarding them to you now to replace those present. Thank you.

Sincerely yours,

for Dr. Aly M. Nawwar, P.Eng.,
Vice President.

AN/lk

311 Legget Drive, Kanata, Ontario K2K 1Z8 - Telephone: (613) 592-2830 - Telex: 053-4730
#16 - 6325 11th Street S.E., Calgary, Alberta T2H 2L6 - Telephone: (403) 253-4883 - Telex: 0382-1972

Please reply to

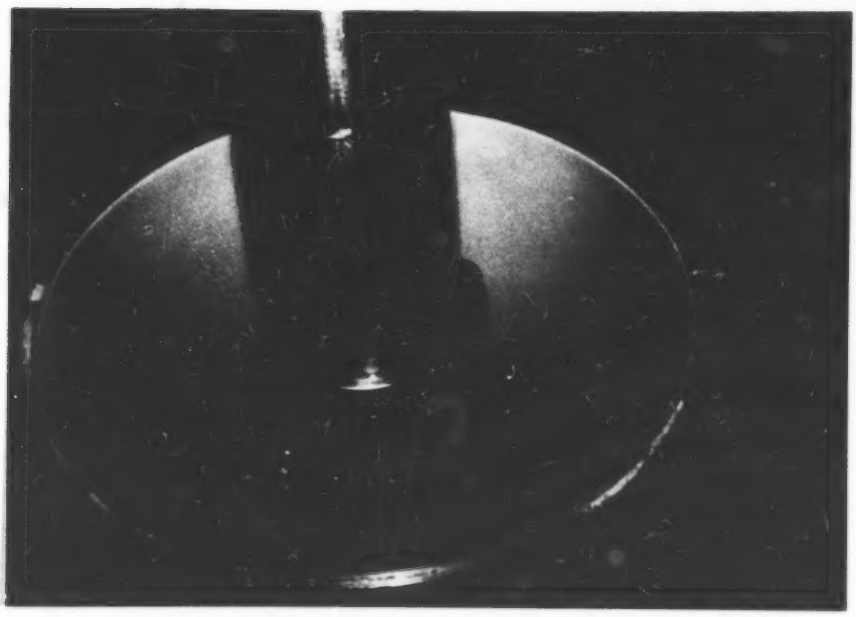
PHOTO NO 1

STEEL SHAFT AND REINFORCING STEEL

PHOTO NO 2

MOLDS WITH SHAFT SECURING DEVICE

PHOTO NO 3

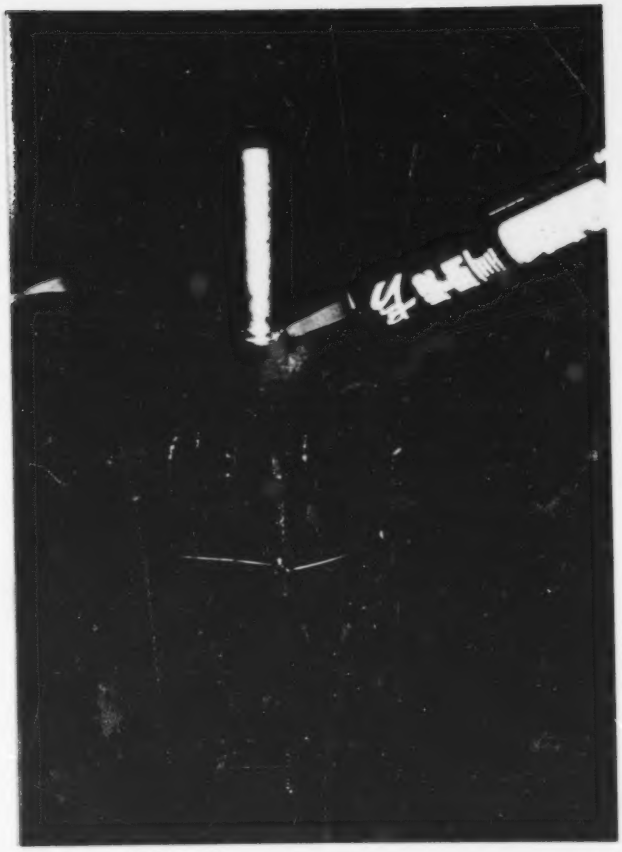


SMOOTH TEXTURE PLASTIC LINER

PHOTO NO 4

ROUGH TEXTURE PLASTIC LINER

PHOTO NO 5



APPLICATION OF SEALER ON SHAFT

PHOTO NO 6

TEXTURE AT MOLD VERTICAL JOINT